CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Sciences

Department of Air Transport

Bc. Dávid Jaš

CURRENT OPERATIONAL POSSIBILITIES OF UNMANNED AERIAL SYSTEMS EXCEEDING 150 KG

Master's Thesis

2020

CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Transportation Sciences
Dean's office
Konviktská 20, 110 00 Prague 1, Czech Republic

K621 .... Department of Air Transport

MASTER'S THESIS ASSIGNMENT

(PROJECT, WORK OF ART)

Student's name and surname (including degrees):

Bc. Dávid Jaš

Code of study programme code and study field of the student:

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Theme title (in English): Current Operational Possibilities of Unmanned Aerial Systems Exceeding 150 kg

Guides for elaboration

During the elaboration of the master's thesis follow the outline below:

- The objective of the thesis is to create a comprehensive guide for manufacturers and operators of UAS exceeding 150 kg to meet current and future unmanned aerial system certification requirements
- Current operational possibilities of UAS exceeding 150 kg with/without a person on board
- Possible procedures for the certification of UAS
- Defining minimum requirements for UAS equipment (UAS exceeding 150 kg with/without a person on board
- Proposal for a certification procedure for UAS with/without a person on board
- Evaluation of advantages and disadvantages

Graphical work range: according to the instructions of the master's thesis supervisor

Accompanying report length: at least 55 text pages (including figures, graphs and tabels as a part of the accompanying report

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FAA Standard Airworthiness Certification Part 23

Regulation L2 - Rules of the Air, Supplement X

Master's thesis supervisor: **Ing. Jan Andrýsek**

Ing. Šárka Hulínská

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L. S.

Kraus

doc. Ing. Jakub Kraus, Ph.D.
head of the Department
of Air Transport

doc. Ing. Pavel Hrubeš, Ph.D.
dean of the faculty

I confirm assumption of master's thesis assignment.

Bc. Dávid Jaš
Student's name and signature

Prague ....July 17, 2019

ČESKÉ VYSOKÉ UČENÍ TECHNICKÉ V PRAZE
Fakulta dopravní
děkan
Konviktská 20, 110 00 Praha 1

K621 ....Ústav letecké dopravy

ZADÁNÍ DIPLOMOVÉ PRÁCE

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Název tématu (anglicky): Current Operational Possibilities of Unmanned Aerial Systems Exceeding 150 kg

Zásady pro vypracování

Při zpracování diplomové práce se řiďte následujícími pokyny:

- Cílem práce je vytvořit výrobcům a provozovatelům UAS nad 150 kg komplexní návod pro splnění současných i budoucích certifikačních požadavků bezpilotních leteckých systémů
- Současné možnosti provozu UAS nad 150 kg bez/s osobou na palubě
- Možné postupy certifikace UAS
- Definování minimálních požadavků na technické vybavení UAS (nad 150 kg bez/s osobou na palubě
- Návrh postupu certifikace UAS bez/s osobou na palubě
- Zhodnocení výhod a nevýhod

ČVUT FD

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Předpis L2 - Pravidla létání, Doplněk X

Vedoucí diplomové práce: **Ing. Jan Andrýsek**

Ing. Šárka Hulínská

Datum zadání diplomové práce: **17. července 2019**

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b) v případě odkladu odevzdání práce následující datum odevzdání práce vyplývající z doporučeného časového plánu studia

L. S.

doc. Ing. Jakub Kraus, Ph.D.
vedoucí
Ústavu letecké dopravy

doc. Ing. Pavel Hrubeš, Ph.D.
děkan fakulty

Potvrzuji převzetí zadání diplomové práce.

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podpis

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CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Transportation Services

Department of Air Transport

CURRENT OPERATIONAL POSSIBILITIES OF UNMANNED AERIAL SYSTEMS EXCEEDING 150 KG

Master’s Thesis

August 2020

Bc. Dávid Jaš

ABSTRACT

The certified category of unmanned aerial systems intended for the transportation of passengers and cargo represents a new branch of aviation in the context of urban air mobility, the aim of which is to transfer part of the population's transport needs in densely populated areas to airspace. This master’s thesis provides an overview of the issue of the certified category of UAS with regard to current and future challenges and problems. The master’s thesis describes the European and local Czech legislative framework concerning UAS. It also deals with the concept of urban air mobility including a description of selected, currently developing projects, risks associated with the operation of the certified-category UAS and challenges in the field of autonomous flying. The current possibilities of integration of unmanned aircraft into air traffic management system are described in more detail with views from competent institutions such as ANS CR. Presented in the thesis is a proposal to expand the U-space system into a form suitable for better integration of unmanned aircraft into the ATM system in the future. The key part of the thesis is the analysis of certification possibilities of the certified category of unmanned aircraft for civilian use. The view of ICAO, EASA, FAA, but also the Czech CAA on current certification options is discussed. The thesis contains a proposal that can serve manufacturers and applicants for type certificates as a guide to the certification process, with an evaluation of the current limitations of certification and a description of the possibilities for future development.

KEY WORDS

unmanned aircraft, legislation, certification, airspace, integration, air mobility, autonomous flying

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SOUČASNÉ MOŽONOSTI PROVOZU BEZPILOTNÍCH LETECKÝCH SYSTÉMŮ S HMOTNOSTÍ NAD 150 KG

diplomová práce

srpen 2020

Bc. Dávid Jaš

ABSTRAKT

Kategorie certifikovaných bezpilotních letadel určených pro přepravu osob a nákladu reprezentuje novou vývojovou větev letectví v kontextu městské vzdušné mobility, jejímž cílem je přesun uspokojování části dopravních potřeb obyvatelstva v hustě osídlených oblastech do vzdušného prostoru. Tato diplomová práce vnáší přehled do problematiky certifikované kategorie bezpilotních letadel s ohledem na aktuální a budoucí výzvy a problémy. Diplomová práce popisuje evropský a místní český legislativní rámec týkající se bezpilotních letadel. Řeší také koncept městské vzdušné mobility s popisem vybraných, aktuálně vyvíjených projektů, rizika spojená s provozem bezpilotních letadel certifikované kategorie a výzvy v oblasti autonomního létání. Rozsáhleji jsou popsané stávající možnosti integrace bezpilotních letadel do služeb řízení letového provozu s vnesením pohledu kompetentní instituce, jakou je ŘLP ČR. Prezentován je zde návrh rozšíření systému U-space do podoby umožňující v budoucnosti lepší integraci bezpilotních letadel do systému ATM. Klíčovou částí práce je analýza možností certifikace certifikované kategorie bezpilotních letadel pro civilní využití. Popsán je pohled ICAO, EASA, FAA, ale také českého ÚCL na současné certifikační možnosti. V práci je obsažen návrh, který může posloužit výrobcům a žadatelům o udělení typového certifikátu jako návod na postup v certifikačním procesu se zhodnocením současných omezení certifikace a popisem možností budoucího rozvoje.

KLÍČOVÁ SLOVA

bezpilotní letadla, legislativa, certifikace, vzdušný prostor, integrace, vzdušná mobilita, autonomní létání

Table of Contents

Acronyms and Abbreviations

AAV	Autonomous Aerial Vehicle
ADS	Airworthiness Design Standard
ADS-B	Automatic Dependent Surveillance – Broadcast
AGL	above ground level
AI	Artificial Intelligence
AIM	Aeronautical Information Manual
AMC	Acceptable Means of Compliance
amdt.	amendment
ANS CR	Air Navigation Services of the Czech Republic
ANSP	Air Navigation Service Provider
ATM	Air Traffic Management
BTS	Bureau of Transportation Statistics
BVLOS	Beyond Visual Line of Sight
ca.	*circa* (“approximately”)
CAA	Civil Aviation Authority
CFR	Code of Federal Regulations
CIS	Common Information Service
CNS	Communication, Navigation and Surveillance
Co.	company
CofA	Certificate of Airworthiness
CS	Certification Specifications
ctd.	cited
CTOL	Conventional Take-Off and Landing
CTR	Control Zone / Control Traffic Region
EASA	European Union Aviation Safety Agency
EC	European Commission
e.g.	*exempli gratia* (“for example”)
etc.	*et cetera* (“and the other things, and so on”)
EU	European Union
eVTOL	Electric Vertical Take-off and Landing
FAA	Federal Aviation Administration (NAA of the USA)
FAB	Functional Airspace Block
FAR	Federal Aviation Regulations
FIS	Flight Information Service
ft	feet
GA	General Aviation

GM	Guidance Material
GNSS	Global Navigation Satellite System
i.e.	*id est* ("that is")
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
incl.	including
IR	Implementing Rules
JAA	Joint Aviation Authorities
JARUS	Joint Aviation Authorities for Rulemaking on Unmanned Systems
kg	kilogram
km/h	kilometers per hour
kn	knot
LIDAR	Light Detection and Ranging
Ltd. *(in German: GmbH)*	limited liability company
LUC	Light UAS Operator Certificate
ML	Machine Learning
MOC	Means of Compliance
MS	Member State
MTOM	Maximum Take-Off Mass
MTOW	Maximum Take-Off Weight
NAA	National Aviation Authority
NASA	National Aeronautics and Space Administration
n.b.	*nota bene* ("note")
NPA	Notice of Proposed Amendment
NTSB	National Transportation Safety Board
PAV	Passenger Air Vehicle
RPAS	Remotely Piloted Aircraft System
RPS	Remote Pilot Station
SAA	Sense and Avoid
SC	Special Condition
SES	Single European Sky
SESAR	Single European Sky ATM Research
sUAS	small Unmanned Aerial System
TCAS	Traffic Collision Avoidance System
TFR	Temporary Flight Restriction
TOL	take-off and landing
TRA	Temporary Reserved Area
TSA	Temporary Segregated Area

UA	Unmanned Aircraft
UAM	Urban Air Mobility
UAS	Unmanned Aerial System
UASP	Urban Airspace Service Provider
UATM	Urban Air Traffic Management
UAV	Unmanned Aerial Vehicle
UN	United Nations
USA	United States of America
USSP	U-space Service Providers
UTM	UAS Traffic Management
VFR	Visual Flight Rules
VLL	very low level
VLOS	Visual Line of Sight
VMC	Visual Meteorological Conditions
VTOL	Vertical Take-off and Landing
ZOLZ	Special Certificate of Airworthiness in the Czech Republic *(in Czech: ZOLZ – Zvláštní osvědčení letové způsobilosti)*

Introduction

In accordance with the technical terminology, the drone, as the notion more familiar and widely used by the lay public, is an unmanned aerial system (UAS) operated without a pilot on board. The weight of currently operated drones varies from miniature nanodrones to large drones used, for example, in aerospace research activities. The gradual progress in the development of unmanned aircraft has led to a fall in their prices making them more accessible to a wider scope of users. The market potential of drones is enormous and creates new job opportunities from which the society may benefit. Drones are commonly used in a wide variety of industries, e.g. in recording and research activities such as power line inspections, construction activities, measurement works or film productions and many others. The general purpose of their use in industries in which they are replacing human labor is optimization of activities and mitigation of risks associated with hazardous works.

However, the rapid development can also be seen in the field of large drones weighing over 150 kg. The technological development of many areas has enabled the emergence of completely new concepts of unmanned aircraft designed for transporting people and cargo, which combine the characteristics of traditional airplanes and drones. Along with the concepts of these novelty aircraft, the concept of the so-called urban air mobility has also emerged, which is based on transferring the fulfillment of part of the transport needs of the population, especially in densely populated metropolitan areas, to airspace in order to avoid further burdens on land transport infrastructure. The development in recent years has been so rapid that the robust aviation regulatory system is unable to respond to it in a timely manner. The increasing spread of large drones is naturally associated with risks related to the safety of their operation regarding potential collisions with air traffic or other obstacles. Another major obstacle to their introduction into service is the absence of a legislative framework at national and international level that would allow these novelty machines, which can be said to represent a completely new development branch in aviation, to be certified for civilian use. Although autonomous unmanned operation is intended with these aircraft in the future, piloted flights can be expected, especially in the initial years of their introduction into operation. Therefore, it is necessary to implement legislation to sensibly regulate the use of unmanned aircraft systems for their safe and environmentally friendly operation, and protection of lives, health, property, and personal data for the benefit of all.

The aim of this master's thesis is to bring more insight into this new field of aviation, about which many academic theses and studies have not yet been written. This master's thesis could therefore contribute to the discussion on the future of the development of unmanned aircraft for the transport of persons and cargo. The aim is therefore to describe the current possibilities of operation of unmanned aircraft exceeding 150 kg from a legislative point of view, to analyze in more detail the possibilities of their integration into the current air traffic management system, to look at some risks associated with their operation, describe current possibilities of certification of these machines for operation and propose a certification procedure, which could be followed by manufacturers and applicants for a type-certificate. Part of the processing of the thesis should also provide an insight into the issue of autonomous flying, which is still relatively problematic in the current state. In conclusion, the thesis aims at describing the possible future way in which unmanned aerial systems exceeding 150 kg become a common part of aviation and serve its various purposes within the urban air mobility.

It should be emphasized that the assignment of this master's thesis was based on the national and European legislation regarding unmanned aerial systems in force at that time, in particular Regulation (EC) No. 2016/2008 (also called the Basic Regulation). For this reason, the title of the thesis mentions the term 'unmanned aerial systems exceeding 150 kg', since under the Regulation in force at that time it was the maximum take-off mass threshold dividing UAS. An updated version of the Basic Regulation – Regulation (EU) No. 2018/1139 of the European Parliament and of Council, as well as the Implementing Regulation No. 2019/947 and Delegated Regulation No. 2019/945, subsequently amended the division of UAS by expiring national rules and introducing a new division of UAS according to the type and conditions of their intended operation into the categories 'open', 'specific' and 'certified'. With respect to the abovementioned Regulations, the thesis deals mainly with the certified category. The term 'unmanned aerial systems in the certified category' and its variations fully replace the original term 'unmanned aerial systems exceeding 150 kg' and its variations. These terms, both mentioned in the thesis, are interchangeable since they do not change the ultimate essence of this master's thesis.

1 Legislation

1.1 European UAS legislation overviews

The following chapter presents a basic overview of the development of legislation related to UAS, serving primarily as an overview of the most important legislative documents affecting the operation of UAS in the EU. It does not deal in detail with the timeline of the development of legislation which can be found on publicly accessible sources.

1.1.1 Types of regulations adopted by EASA

In order to better understand the process of developing the regulatory framework, it should be mentioned that EU regulations issued by the European Union Aviation Safety Agency (EASA) are usually organized in the three following levels [1,2]:

1. **Basic Regulation –** basic principles and essential requirements
2. **Implementing Rules (IR) –** binding in their entirety and used to specify a high and uniform level of safety and uniform conformity and compliance. They are adopted by the European Commission in the form of **Regulations**
3. **Acceptable Means of Compliance (AMC) and Guidance Material (GM)**
   - AMC is non-binding and serves as means by which the requirements contained in the Basic Regulation and the Implementing Rules can be met
   - GM is non-binding explanatory and interpretation material on how to achieve the requirements contained in the Basic Regulations, IRs, AMCs and the CSs which also contains information, including examples, to assist the user in the interpretation and application of them.

Another example of EASA's so-called soft law regulations are the **Certification Specifications (CS)** which are non-binding technical standards adopted to meet the essential requirements of the Basic Regulation and where industry standards developed by standardization bodies could be used to provide the means to comply with the safety objectives or provide methods to perform risk assessments.

1.1.2 EASA drone operation common rules proposal

The EASA, in response to the increase in the need of drone regulation introduction, issued a 'Proposal to create common rules for operating drones in Europe', mandated by the European Commission in 2015. This document, entitled A-NPA 2015-10, contains a description of at that time the current state of the legislation related to drones. Regulation (EC) No 216/2008 ("Basic Regulation") required unmanned aircraft systems exceeding 150 kg to be regulated similarly to other manned aircraft, whereas unmanned aircraft below this mass should only be regulated at EASA member state level [3,4].

In A-NPA 2015-10, all interested parties were invited to submit comments and suggestions for discussion and possible incorporation into regulatory changes. The document proposed to include both commercial and non-commercial activities in safety regulations and introduced three categories of operation of unmanned aircraft systems based on the risk that their operations may pose to third parties – persons and property. Following three categories were proposed [3]:

1. Open category
2. Specific category
3. Certified category

Open category (low risk) requires ensuring safety through a minimum set of rules, operational constraints and standards, the enforcement of which is mainly to be provided by police. Therefore, the proposals within the document describe restrictions on the operation of drones without a regulatory load, while ensuring safety for all third parties. For example, operation in this category requires visual contact with the drone, mass lower than 25 kg, a flight in a maximum height of 150 m above ground level (AGL) and so-called geo-fencing concept that sets out specific areas which the drone cannot enter.

Specific category (medium risk) requires an authorization obtained from the Aviation Authority based on an operator's risk assessment. The Drone Operations Manual should include a set of measures taken to reduce or mitigate the risk. This category shall include any traffic exceeding the restrictions for 'Open category'.

Certified category (higher risk) sets requirements comparable to those for crewed aircraft. The category should include large drones operated by small or large organizations. In the 'Certified category', drones are treated in a similar way to manned aircraft, thus their airworthiness must be certified. Supervision of certification and approval by organizations approved for maintenance, operation, training, air traffic management and aerodrome operation should fall within the competence of national aviation authorities.

The reason for division UAS traffic operation based on the risk posed to third parties is that the amount of damage caused may not be proportional to the size or mass of the drone being operated. A heavy-weight unmanned aircraft operating over the open seas poses lower risk than a small drone flying over spectators at a stadium. The document also proposed that EASA Member States would determine which of their bodies or organizations should be responsible for enforcing these rules [3].

1.1.3 EASA Technical Opinion

Following the publication of the 'Proposal to create common rules for operating drones in Europe', on December 18, 2015, EASA published the 'Technical Opinion – Introduction of a regulatory framework for the operation of unmanned aircraft' (hereinafter referred to as the "Technical Opinion"). The purpose of the Technical Opinion was the intention to [1]:

- lay the foundation of future work, notably the development of the necessary implementing rules in accordance with the EASA's rulemaking process;
- illustrate the articles and requirements on UAS;
- serve as guidance for EASA Member States that have no rules for small unmanned aircraft or plan to modify their existing ones to ensure consistency with the intent of the future EU rules; and
- provide a road map presenting the steps to be taken in the future.

The Technical Opinion is an extension of A-NPA 2015-10. It includes 27 specific proposals for a regulatory framework and for low-risk operations of all unmanned aircraft irrespective of their maximum certified take-off mass. The regulatory framework presented in the Technical opinion is proportionate, operation-centric, risk- and performance-based. To explain these attributes of the framework, the Technical Opinion states as follows [1]:

- **proportionality –** the requirements associated with unmanned aircraft activities are tailored to the risk associated with each activity;
- **operation-centric –** the regulatory framework is based on the risk posed by UAS operations as there is nobody on board an unmanned aircraft and thus the consequence of loss of control are highly dependent on the operating environment. A crash in an unpopulated area would merely lead to the loss of the unmanned aircraft whereas if occurred in a major city, the same event may have different, more serious consequences;
- **risk-based –** the level of risk depends on the energy (kinetic, potential and internal), the size and the complexity on the unmanned aircraft; the population density of the overflown area; and the design of the airspace, the density of traffic and the services provided therein. The regulatory framework applies to both commercial and non-commercial operations as identical unmanned aircraft might be used for both activities with the same risk to uninvolved parties;
- **performance-based –** performance-based regulation is a regulatory approach that focuses on desired and measurable outcomes.

The Technical Opinion contains the specificities of unmanned aircraft such as safety, security and privacy risk, benefits, risk mitigations and the description of the three above mentioned categories of unmanned aircraft. The integration of unmanned aircraft into the airspace and the aviation system as well as addressing safety issues therefore requires cooperation of all involved parties such as regulators within and outside the European Union, industry, standardization bodies, air navigation service providers and research institutes [1]. Considering its broad scope, the Technical Opinion merely presents general instructions and steps that need to be undertaken in the future and is only one step in the development of rules for unmanned aircraft.

1.1.4 Notice of Proposed Amendment 2017-05

As EASA states in its 'drones regulatory framework background' [5], based on the market's needs, priority has primarily been given to the development of a regulation for operations in **open** and **specific** category with the plan to develop the regulation framework for operations in **certified** category in 2018 and 2019. Following the publication of the Technical Opinion, EASA drafted and published in May 2017 the 'Notice of Proposed Amendment', entitled NPA 2017-05 with subtitle 'Introduction of a regulatory framework for the operation of drones – Unmanned aircraft system operations in the open and specific category' [6].

In accordance with the Basic Regulation, the regulation of unmanned aircraft systems with a maximum take-off mass (MTOM) of less than 150 kg falls within the competence of the European Union member states. This leads to a fragmented regulatory system hampering the development of a single EU market for UAS and cross-border UAS operations. According to NPA 2017-05, this issue is aimed to be resolved by a newly proposed Basic Regulation which extends the competence of the EU to regulate all UAS regardless of their MTOM. The NPA proposes to create new regulation defining the measures to mitigate the risk of operations in [6]:

- the open category through a combination of limitations, operational rules, requirements for the competence of the remote pilot, as well as technical requirements for the UAS; and
- the specific category through a system including a risk assessment conducted by the operator before starting an operation, or the operator complying with a standard scenario, or the operator holding a certificate with privileges.

In the NPA EASA states that based on the comments received from stakeholders, it will develop an opinion containing a new proposed draft of Commission implementing regulation laying down rules for unmanned aircraft systems operations. The opinion will be subsequently submitted to the European Commission in order to be used as a technical basis in preparation of new EU regulation [6].

The NPA 2017-05 consists of two documents, A and B. The document A contains the explanatory note and the proposed draft rules. In it there can be found information about the development of the NPA – why was it developed, what rules need to be changed, how this is possible to achieve, etc. There is also information about the general issues related to UAS operations, open-category, and specific-category issues and what are the benefits and drawbacks of the proposals. A draft of the new legislation listing very specific rules related to the 'open' and the 'specific' category is also included.

Part B of the document contains the full impact assessment for the rulemaking task. It is stated that the use of UAS can bring benefits such as a safer way to do business without risk to human lives, additional business, efficiency, and creation of employment opportunities. On the contrary, operating UAS raises concerns about safety, security, privacy, data protection, and the environment. Therefore, in order to address those concerns in a satisfactory way, the impact assessment was developed whose purpose is to provide a quantitative and qualitative analysis, based on which the most beneficial rulemaking option is selected; and an understanding of the various impacts of all analyzed options [6].

Part B of NPA 2017-05 also contains information related to at that time current EU framework, current regulatory framework at MS level, EASA consultation strategy, and introduction to various issues and their detailed analysis. The list of issues includes lack of clarity and non-harmonized definition of categories of UAS boundaries, lack of protection of sensitive areas, inadequate technical requirements, lack of airspace classification and of rules for low-level operations, inadequate competences of remote pilots, etc. Objectives and an introduction on options for achieving them are also part of the document, as well as the list of options for the open and the specific category. Finally, the documents contain information on UAS registration possibilities, their impacts, and a comparison [6].

1.1.5 Opinion No 01/2018

After a political agreement between the Council, the European Commission and the European Parliament was reached on 22 December 2017, which resulted in the proposal of a new Basic Regulation (covered later in the work), EASA published an Opinion No 01/2018 which extended the competence of the EU to cover the regulation of all civil unmanned aircraft systems, regardless of their MTOM, and introduced a regulatory framework for the operation of UAS in the 'open' and the 'specific' category. According to the Opinion, the proposed regulations will provide flexibility to MSs to create zones within their territories where the use of UAS would be prohibited, limited, or facilitated. Additionally, two acts were proposed that follow different adoption procedures, as defined by the new Basic Regulation [7]:

1. **a delegated act** that defines the conditions for making UAS available on the market and the conditions for UAS operations conducted by a third-country operator; and
2. **an implementing rule** that defines the conditions to operate UAS and the conditions for registration.

The main aspects of the regulation for the 'open' and the 'specific' category proposed by the Opinion are such that they provide a framework to safely operate drones while allowing the industry to innovate and continue to grow. The risk posed to people on the ground and to other aircraft, as well as privacy, security and data protection issues created by operating the drones are also considered. The regulation defines the technical and operational requirements such as a remote identification or a geo-awareness system that informs the remote pilot when a drone is entering a prohibited zone. It also addresses the qualifications of the pilots. Drone operators will have to be registered, except when they operate drones lighter than 250 grams. The newly proposed legislation combines Product legislation and Aviation legislation and allows a high degree of flexibility for EASA MSs to be able to define zones within their territory where drone operations may be prohibited or restricted, or where some requirements may be alleviated [5].

Along with the Opinion, a revised version of draft acceptable means of compliance (AMC) and guidance material (GM) were published to lay down rules and procedures for the operation of UAS. The draft is divided into two subparts which specify in detail the rules for the 'open' and the 'specific' category, and it provides information on the Light UAS Operator Certificate approval [8].

1.2 EASA Legislation on UAS exceeding 150 kg

The previous part of the work was devoted to unmanned aircraft systems in general. Above all, the development of legislation concerning the rules of their operation has been described. In the recent period, the development of legislation has focused primarily on UAS in the 'open' and the 'specific' category as most of the currently operated civil drones fall into these categories. EASA has had to respond to the raising number of UAS operated, particularly in the context of raising concerns associated with their operation, such as safety, security, privacy, data protection, and the environment. EASA also had to respond to lighter UAS being only subject to various non-uniform rules on the level of EU members. The next part of the work deals with the UAS exceeding 150 kg.

Regulation (EC) No 216/2008 ("Basic Regulation") applies to the design, production, maintenance and operation of aeronautical products, parts and appliances, as well as personnel and organizations involved in the design, production and maintenance of such products, parts and appliances; and personnel and organizations involved in the operation of aircraft. Aircraft except those referred to in Annex II of the Regulation shall therefore comply with the essential requirements for airworthiness for:

- product integrity;
- airworthiness aspects of product operation; and
- organizations (including natural persons) undertaking design, manufacture, or maintenance.

These requirements are laid down in detail in Annex I of the Regulation (EC) No 216/2008 [9]. Compliance of aircraft with the essential requirements for airworthiness is proven by a type-certificate that all products shall have; specific certificates that are issued for parts and appliances; an individual certificate of airworthiness that is issued for each aircraft when it conforms with the type design approved in its type-certificate and when relevant documentation, inspections and tests demonstrate that the aircraft is in condition for safe operation. Also, organizations responsible for the maintenance of products, parts and appliances and organizations responsible for the design and manufacture of products, parts and appliances shall demonstrate their capability and means to discharge the responsibilities associated with their privileges. Other requirements for aircraft laid down in the Basic Regulation concern environmental protection, pilots, air operations, rules for aircraft used by a third-country operator, oversight and enforcement, recognition of certificates, etc. Some basic requirements for pilots, pilot licensing and air operations stated in this Regulation are, for example, as follows [9]:

- a person undertaking training to fly an aircraft must be sufficiently mature educationally, physically, and mentally to acquire, retain and demonstrate the relevant theoretical knowledge and practical skill (Annex III, paragraph 1.a.1.); or
- a flight must not be performed if the crew members and, as appropriate, all other operations personnel involved in its preparation and execution are not familiar with applicable laws, regulations and procedures, pertinent to the performance of their duties, prescribed for the areas to be traversed, the aerodromes planned to be used and the air navigation facilities relating thereto (Annex IV, paragraph 1.a.).

As mentioned above, Annex II to the Regulation (EC) No 216/2008 contains a list of aircraft categories to which requirements for airworthiness stated in Article 4 of the Regulation are not applied. The list contains a category called 'unmanned aircraft with an operating mass of no more than 150 kg'. Therefore, unmanned aircraft exceeding an operating mass of 150 kg shall comply with all the requirements for airworthiness of manned aircraft which points out the obsolescence of the legislation and the need for its renewal.

In response to this need, on 22 August 2018 EU has issued a Regulation (EU) 2018/1139 of the European Parliament and of the Council on common rules in the field of civil aviation and establishing EASA, which amended and repealed several regulations, including the Regulation (EC) No 216/2008, and has become the new "Basic Regulation". In the new Basic Regulation, a whole section devoted to general requirements for UAS has been processed compared to the original Regulation (EC) No 216/2008.

The new section of the new regulation is the Section VII – Unmanned aircraft and contains Articles 55 to Article 58. Article 55 sets an essential requirement for UA which is the compliance with requirements set out in Annex IX to this Regulation which are described in detail further in the text. Based on Article 56, a certificate may be required for the design, production, maintenance and operation of unmanned aircraft and their engines, propellers, parts, non-installed equipment and equipment to control them remotely, as well as for the personnel, remote pilots, and organizations involved in those activities. The certificate shall be issued upon application, has the applicant demonstrated the compliance with delegated and implementing acts. It may also be amended to add or remove limitations, conditions, and privileges; but also limited, suspended, or revoked when its holder no longer complies with conditions for its issuing and maintaining. According to Article 56, Member States shall also ensure storage of information about registration of UAS and of operators of UAS in digital, harmonized, and interoperable national registration system which is accessible to other Member States through the repository of information. This Regulation provides the possibility for Member States to lay down national rules for UAS operations in case they regard security, privacy protection and personal data protection. Article 57 contains implementing acts in order to ensure the uniform implementation and compliance with the essential requirements for UAS. The last article of Section VII, Article 58, contains delegated powers which the Commission is empowered to adopt to lay down detailed rules with regard to specific conditions, for example, the conditions under which unmanned aircraft are required to be equipped with necessary features and functionalities, maximum operating distance, altitude, zone entry restrictions, etc. And they also regard conditions and procedures for issuing, maintaining, amending, limiting, suspending, or revoking the certificates [10].

The next part of the new Basic Regulation, which deals with UAS in detail, is Annex IX. Annex IX contains general essential requirements for the design, production, maintenance, and operation of UAS. It contains additional essential requirements for airworthiness, organizations, persons involved in operation of UAS, air operations and essential requirements relating to electromagnetic compatibility and radio spectrum for UAS to operate on frequencies allocated for protected aeronautical use. It also concludes essential environmental requirements for UAS referring to Annex III; and essential requirements for registration of UAS and their operators and marking of UAS [10].

Regulation (EU) 2019/945 and Regulation (EU) 2019/947

On 12 March 2019, the European Commission adopted a Delegated Regulation (EU) 2019/945 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems which among other things applies to UAS operated under the rules and conditions of the 'specific' and 'certified' categories of UAS operation. The regulation sets requirements for UAS operated in the 'certified' category stating that the design, production, and maintenance of UAS must be certified if the UAS [11,12]:

- has a characteristic dimension of 3 m or more, and is designed to be operated over assemblies of people (gatherings where persons are unable to move away due to the density of the people present);
- is designed for transporting people;
- is designed for the purpose of transporting dangerous goods and requiring a high level of robustness to mitigate the risks for third parties in case of accident.

In addition, UAS operations must be classified as UAS operations in the 'certified' category where the competent authority, based on the risk assessment provided, considers that the risk of the operation cannot be adequately mitigated without the certification of the UAS and its operator, and without the licensing of the remote pilot. An operational risk assessment should describe the characteristics of the UAS operation, propose adequate operational safety objectives, identify the risks of the operation on ground and in the air, identify a range of possible risk mitigating measures and determine the necessary level of robustness of the selected mitigating measures in such a way that the operation can be conducted safely. All the rules for conducting an operational risk assessment are described in detail in Article 11 of the Implementing Regulation (EU) 2019/947 on the rules and procedures for the operation of unmanned aircraft which has been issued alongside the Delegated Regulation (EU) 2019/945.

1.3 Czech Legislation on UAS exceeding 150 kg

The previous part of the work was devoted to EASA legislation, particularly to the Basic Regulation and its renewed version which contains very general information and basic requirements at EU and national levels on UAS. In this chapter, Czech legislation will be described with regard to European legislation.

The operation of aircraft in the Czech Republic is subject to national Regulation L2 – Rules of the Air. In Title 3, paragraph 3.1.9. Remote-controlled aircraft shall be stated that *"an unmanned system, as set out in Annex II to Regulation (EC) No 216/2008 of the European parliament and of the Council, exempt from EASA competence and retained in national competence, shall be operated in accordance with the terms of Supplement X to this Regulation, unless otherwise specified for certain categories of unmanned systems in this Title".* Operation of unmanned aircraft systems in the territory of the Czech Republic is therefore subject to Supplement X to Regulation L2. The Civil Aviation Authority of the Czech Republic lists three categories of UAS in the overview of essential requirements for UAS [13]:

- aircraft models with a maximum take-off mass up to 25 kg;
- unmanned aircraft up to 25 kg – recreational and sport flying;
- unmanned aircraft – other (regardless of maximum take-off mass).

Individual categories differ in the need for licensing and registration, usability for professional activities, the binding nature of Supplement X and the insurance requirement. Unmanned aircraft, the operational possibilities of which are the subject of this thesis, fall into the last category.

Clause 4 of Supplement X states that an unmanned aircraft can only be operated under the pilot's supervision in order to maintain continuous visual contact unless the CAA of the Czech Republic grants an exception. According to Clause 5, the person who remotely operates the unmanned aircraft, irrespective of the level of automation of the flight management system, is responsible for conducting a safe flight, including pre-flight preparation and inspection. Therefore, those rules do not currently allow the operation of unmanned systems with a fully autonomous control system.

Supplement X subsequently sets out additional rules for the operation of unmanned systems such as keeping records in a logbook, continuing airworthiness, flight termination, operating areas, protection zones, meteorological minima, rules for dangerous cargo, cargo dropping, pilot movement, aerial public appearances, compliance with other legislation, propulsion and event reporting. Clause 16 lays down additional conditions for the operation of an unmanned aircraft. For unmanned aircraft above 150 kg, the essential requirements are those for aircraft above 25 kg and for unmanned aircraft operated by pilot, as shown in the following modified section of Table 1 of Supplement X [14]:

Table 1 – Additional conditions for UAS operation according to Clause 16 of Supplement X [14]

maximum take-off mass		> 25 kg		UAS operated outside the pilot's visual contact
purpose of use		recreational and sports	gainful, experimental, research	
requirement				
1	aircraft registration	yes	yes	yes
2	pilot registration	yes	yes	yes
3	practical and theoretical test for the pilot	yes	yes	yes
4	permission to fly	yes	yes	yes
5	aerial works / personal activities permission	not possible	yes	not possible
6	UAS marking: ID label / ID label + registration plate	yes / no	yes / yes	yes / yes
7	min distance (m): take-off, landing / persons, structures / populated area	safe but at least 50/100/150	safe but at least 50/100/150	safe but at least 50/100/150
8	insurance: regular traffic / airshow	acc. Regulation No 785/2004	acc. Regulation No 785/2004	acc. Regulation No 785/2004
9	surveillance	yes	yes	no
10	failsafe system	yes	yes	yes
11	UAS operations manual	no	yes	no
12	occurrence reporting	yes	yes	yes

The certification of aircraft in the Czech Republic at the national level is subject to Regulation L8 – Airworthiness of Aircraft. At European Union level (EASA) it is subject to the certification procedure CS-23 – Certification Specifications for Normal, Utility, Aerobatic and Commuter Category Airplanes.

The original division of the UAS by MTOM was established by Regulation (EC) No. 216/2008 (Annex II), which set the limit value for drones as MTOM 150 kg. UASs with MTOMs below this value were subject to conditions imposed by individual EU member states on their own. UASs exceeding 150 kg were subject to EASA rules. However, there were no operational conditions developed and established, only the certification conditions were set uniformly. The operational conditions were determined by the member states themselves, in the case of the Czech Republic, this was in particular the already mentioned Supplement X to the Regulation L2. This basic Regulation was repealed from 11 September 2018 and replaced by Regulation (EC) No. 2018/1139, in which UASs are already dealt with without regard to MTOM. In consequence of the new basic regulation, the UASs are subject to the European Commission Implementing Regulation No. 2019/947 and Delegated Regulation No. 2019/945. The most significant change worth mentioning is the expiry of the national rules from 31 December 2020 and the determination of a new division of the UAS according to the type of operation in the open, specific, and certified category. These categories have already been described in the chapter 1.1.2 above. Given that this area of aviation is very lively and dynamically evolving, new regulations are issued quite often. It can therefore be assumed that the chapters of this thesis on UAS legislation, both national and European, will lose their relevance not long after the thesis is completed.

2 Urban Air Mobility

The idea that people and cargo will use flying drones for transportation in cities and suburban areas and that drones will become another alternative to increasing traffic on roads may have seemed to be the domain of science fiction until recently. However, current trends in the development of materials and technologies have greatly accelerated this new trend in transport and aviation. As introduced in the following chapters of the thesis, there are already many concepts of passenger drones having passed flight tests and many other startups are still developing their own projects. The European Commission, EASA, Eurocontrol and aviation authorities of EU member states are supporting this new trend in aviation in Europe by preparation for gradual integration of this field of aviation industry into regular aviation.

Urban air mobility refers to a concept of urban or suburban transportation systems that move people and goods by air and are being developed in response to less and less viable land transport infrastructure in densely populated areas. Many companies involved in the development of urban air mobility, such as Airbus, say urban air mobility may positively contribute to a multimodal mobility system and help build more livable cities. Currently, the urbanization rate is 55% with more than 4,2 billion people of the world's population living in urban areas (2018 data). It is estimated that this proportion will increase to 68% by 2050, with close to 90% of this increase taking place in Asia and Africa [15].

The transport needs are increasing with the constantly increasing urban population, resulting in an unprecedented onslaught on road infrastructure and the environment. Urban air mobility may therefore be perceived as an alternative, attractive and environmentally friendly form of transport ensuring sufficiently fast and comfortable mobility for a wide range of people and revolutionizing the urban mobility experience as with this concept implemented the daily commute will no longer be dictated by road and rail networks. In addition to the idea of air mobility for its own private purposes and interests, it can be seen as a means of saving lives and property or maintaining safety of the people provided that the safety of its own operation is ensured. In densely populated areas with congested roads and limited ground access, such drones can be used as ambulances or fire-fighting vehicles, and other services of general interest. Their use is limited only by the imagination of individuals.

The UAM concept includes not only large passenger and cargo drones, but also other drones that move in the urban environment. In particular, drones intentioned for the transport of medical supplies or for the transport of transfusion products and blood derivatives. Medical delivery drones are particularly important in developing countries with poor road infrastructure, but also in dense urban areas where car delivery is no longer effective. The UAM concept thus aims to change the traditional thinking of urban space and spatial planning from the classical two-dimensional to the conceptual perception of the urban environment as three-dimensional. It means systematic thinking about a height model of a city and also support of future corridors for medical drones or infrastructure in the form of skyports on the roofs of high-rise buildings for passenger transport [16].

Projects of UAS intentioned as air taxis sit at the convergence of trends in urban demographics and rapid improvements in batteries, advanced sensors, mass-produced lightweight composite structures, etc. Battery safety and energy density are now adequate and sufficient for airborne applications. Low-cost, reliable avionics are becoming universally available, leveraging years of unmanned aerial vehicle development. These advanced avionics will enable electric vertical take-off and landing aircraft (eVTOLs) to navigate with high precision, exchange information digitally, and respond to changes in flight conditions autonomously. Mature obstacle detection and avoidance technology can enable safe aircraft take-off and landing and provides reliable collision avoidance in flight. At initial launch, many eVTOLs will have pilots on board. With time, however, these aircraft will mature to a stage where they will operate autonomously. Recent advances in automated composite manufacturing and assembly show that small, lightweight vehicles can be produced at high volumes at significantly lower costs. All these trends, along with the rising transportation challenges in metropolitan areas make the case for a new generation of personal aerial vehicles [17].

The recent convergence of several factors such as the rise of on-demand transportation that has come with the expanding implementation of smart technologies and so-called sharing economy, more precise and reliable CNS technologies, and quieter aircraft, places UAM concept within reach of more people. The UAM infrastructure, e.g. skyports and vertiports, and infrastructure-related requirements and customer demands may provide an opportunity to build new businesses and create new jobs in transportation industry. The development of the infrastructure across wide metropolitan areas will be critical to the growth of the UAM industry as the number and location of skyports will drive the number of UAM flights that a city is able to accommodate [18].

In order to extend the applicability of this mode of transport to the widest possible territory and for as many UAS types as possible, the infrastructure will need to be highly standardized in order to guarantee applicability of vertiports to many users. Since most of the concepts of certified UAS being developed are to be electrically powered, it will also be necessary to consider standardizing charging connectors or replaceable batteries, which, for example, can be stored on-site in a charged state and be replaced in a minimized time after landing. Similar to standard commercial fixed-wing aircraft transport, where there is an effort to minimize the ground handling time of the aircraft at the airport. The UAM industry may expand with the growth of eVTOL availability and can be a contributing factor to bolstering multi-modal transit system with higher flexibility of transportation networks.

2.1 Current projects in development

The concept of a personal aerial vehicle providing door-to-door transportation is not a new idea. The so-called flying car, a "predecessor" of a drone that has never reached production status, became an immensely popular theme in various fantasy and science fiction stories in the 20th century. One of the first visionaries to support the realization of the concept of a flying car was an industrialist and the founder of the Ford Motor Company, Henry Ford, who introduced a single-seat aircraft – *Ford Flivver* – whose original name – *Model T of the Air* – was derived from the famous *Ford Model T*, one of the most influential cars of the 20th century [19,20].

Modern day large drones require minimal ground infrastructure compared to land transportation systems, reduce travel distances, save time and energy and represent a new, more environmentally friendly and more efficient way to travel since when powered by green electricity, they will produce zero emissions. When compared to traditional airplanes, the infrastructure demands and space requirements for UAS are significantly reduced. They lack the need for a runway since landings and take-offs are performed on a relatively small area and thus the land area needed is much smaller. If they are to be used for urban transport, their development must go hand in hand with the development of drone-related necessary infrastructure such as skyports, which, for imagery, would resemble heliports in terms of design and appearance with their own specific features.

Use of drones for general transport of persons and goods, especially within urban areas, creates a whole range of new problems and challenges, of which the most substantial is to maintain the safety of their operation. Large drone flying over people and buildings, especially in dense urban areas, can, in the event of failure in flight, landing or take-off, seriously endanger overall safety and put human lives and property at risk. The extension of their everyday use is therefore conditioned by the elaboration and implementation of legislation that will strictly lay down conditions for their certification for operation and ensure sufficient level of safety. Nevertheless, this does not deter many newly emerged startups around the world from building on the urban air mobility trend seeing in the matter the way people will travel and transport goods in the future. In addition, traditional aircraft manufacturers like Boeing and Airbus have also joined the development with their own projects such as Aurora or Vahana. The following subsections of this chapter describe several examples of UAS projects being developed around the world within the concept of urban air mobility.

2.1.1 EHang

Figure 1 – Visualization of the autonomous aerial vehicle EHang AAV [21]

The EHang project represents a series of passenger UAS of a Chinese company Beijing Yi-Hang Creation Science & Technology Co., Ltd. The company declares its EHang is a world's leading autonomous aerial vehicle (AAV) technology platform whose mission is to make safe, autonomous, and eco-friendly air mobility accessible to everyone. It also provides customers in various industries with AAV products and commercial solutions such as urban air mobility, smart city management and aerial media solutions [22].

The company claims that EHang AAV is designed with full redundancy i.e., if one set of the power system are operating abnormal, the vehicle can still operate a normal flight plan and ensure the safety of the passenger together with the vehicle. EHang AAV was designed to be a hundred percent with green technology, powered by electricity only. The vehicle has embedded with a fail-safe system. If any component malfunctions or disconnects, the aircraft will immediately land in the nearest possible area to ensure sufficient level of safety [22].

Unfortunately, the amount of information about the EHang project the company currently provides is very limited. From which is currently known and published, EHang AAV is to be an autonomous UAS serving to transport two passengers and that the company heavily relies on automation.

In early April 2019, EHang took part at the 2019 4GAMECHANGERS Festival that was held in Vienna, Austria, where they held the first public passenger flight demonstration with EHang AAV in Europe. Seventeen media representatives took part in the flight which was later commented on by the founder, president and CEO of EHang, Hu Huazhi, who said: *"UAM has entered our lives. It will permanently change the way people travel. We hope this aircraft will carry our hope for the future and span its wings in the sky of historical Austria!"* [23]

On 20 August 2019, EHang announced that it has become the world's first company to achieve certificate of UAS safety level II for AAVs. The certificate was issued by the China Academy of Civil Aviation Science and Technology and was internationally recognized among member organizations of the China National Accreditation Service for Conformity Assessment. Also, in August, EHang performed another passenger carrying AAV demonstration flight at the 2019 Northeast Asia Expo in Changchun. Similar public demonstration flights have been previously completed in several Chinese cities and other countries, where for example, in addition to Vienna, they took place in Netherlands (16 April 2018 [24]) and Qatar (11 October 2018 [25]). EHang claims these demonstration flights ought to show the public that autonomous flying taxis are not a thing of the future, but are already here nowadays.

2.1.2 Lilium Jet

Figure 2 – Visualization of the Lilium Jet [26]

Lilium Jet is a project of a German company Lilium GmbH that is being developed as an electrically powered commuter aircraft capable of vertical taking-off and landing (VTOL). The company was founded by four engineers at the Technical University of Munich. The Lilium Jet is a tilt jet aircraft with 36 engines mounted on its flaps, each acting on a ducted propeller. The aircraft consists of an egg-shaped fuselage with main wings located at the rear of the aircraft and a smaller vertical stabilizer on the front tip. Of the total number of engines, there are 12 on the frontal vertical stabilizer and 24 on the main wings. The propellers and engines are each installed in tiltable parts which are pivoted downwards for vertical take-off to generate initial vertical lift and then gradually aligned in a transition flight to a horizontal position to generate forward thrust while all the lift is generated by the wings as in a "traditional aircraft". The company claims engines used in the aircraft are unique as they do not create the sort of noise associable with a helicopter or a commercial jet engine thanks to their ducted design capturing and dissipating noise before it leaves the engine [26,27].

Lilium also emphasizes the reduction of complexity as the aircraft is constructed with no tail, no rudder, no variable pitch, no folding propellers, no gearboxes, no oil circuits and with only one moving part in the engine. The company states that the fewer components an aircraft contains, the safer and more affordable it becomes [26]. The statement might be partially true, although the context of safety could be argued.

From the theory of reliability, the fewer components the system has, the more reliable it is since fewer system elements are susceptible to failure [28]. It is quite questionable whether increased reliability of a system automatically means a higher level of overall safety. Lilium Jet, however, is being certified to standards set by EASA in Europe and Federal Aviation Administration (FAA) in the United States, which ensures the required level of safety, and is also built on the principle of ultra-redundancy. With its 36 independent electrically powered engines and a triple-redundant flight control computer, the safety of the aircraft would not be compromised by failure of any one component [26].

Aircraft development process was carried out in numerous steps, from which it is worth mentioning that the first half-scale demonstrator – *Falcon* – was launched back in 2015. The first unmanned flight of the full-size two-seat prototype – *Eagle* – took place on 20 April 2017 [27]. In connection with the technical specifications, the final product – *Lilium Jet* – is designed as an autonomous UAS with capacity for 5 passengers planned for 2025. Empty weight of the aircraft will be 440 kg with the MTOW of 640 kg. The cruising speed of the aircraft should be around 150 kn (280 km/h), with the possibility of the aircraft reaching a maximum speed of 160 km (300 km/h). The Lilium Jet should be capable of traveling up to a range of 300 km, thus with a maximum flight time of 60 minutes. In this way the aircraft should not only be able to connect urban and suburban areas, but cities to one another as well [26,29]. The aircraft is certified according to EASA CS-23 in Europe and FAA Part 23 in the USA using various exemptions.

2.1.3 Volocopter

Figure 3 – Visualization of the Volocopter Velocities [30]

Volocopter GmbH is a German aircraft manufacturer specializing in the design of electric multirotor helicopters in the form of ready-to-fly aircraft, designed for air taxi use. Volocopter product development dates to 2011, when the company launched its first single-seat prototypes *Volocopter VC1* and *VC2.* Gradually, the company evolved the prototypes into double-seat models designed for one pilot and one passenger. Specifically, these were the models *VC200* and *VC2X*, from which arose the design of their latest model – *VoloCity* [30].

Volocopter models are based on the design of a "standard drone". The top of the aircraft is formed by a circular structure, around the perimeter of which in two concentric circles are located 18 electrically powered rotors generating lift and enabling vertical movement and forward flight. Under this structure, as shown in Figure 3, there is a suspended cabin for a pilot and a passenger.

Volocopter is not intended for autonomous flight. The company itself claims that all Volocopters are electrically powered air taxis developed for safe, manned flight in inner cities in order to bring passengers to their destination emission free. The company also claims that the Volocopters are extremely safe since, for example, the *VoloCity* model is designed to meet standards set out by EASA *(EASA SC-VTOl-01, n.b.)*. *VoloCity* is to become the first commercially licensed Volocopter, developed according to the EASA standards and requirements. The aircraft features multiple redundancy systems, ensuring a fail-safe operation which include rotors, electric motors, batteries, avionics, and display. Communication networks of the aircraft are connected by fiber optic cable, so-called "fly-by-light". The aircraft is also claimed to be noticeably quiet thanks to its 18 rotors acoustically operating within a narrow frequency range and very simple to maneuver since around a hundred microprocessors ensure its stability and control. Altitude control, balance and landing is managed by a control stick and Volocopter should automatically hold its position even in case a pilot lets go of it. The following Table 2 shows some technical specifications of the *VoloCity* Volocopter:

Table 2 – Technical features of VoloCity Volocopter [30]

Capacity	2 pax incl. hand luggage
Aspired Certification	EASA SC-VTOL, category enhanced
Power type	electric / batteries
Operating weight empty	700 kg
Maximum payload	200 kg
MTOM	900 kg
Range	35 km
Maximum airspeed	110 km/h
Engine type	18 x Brushless DC electric motor (BLDC)
Power supply	9 Lithium-ion battery packs

German Ultralight Flight Association was testing the Volocopter on behalf of the German Federal Ministry of Transport and Digital Infrastructure from 2013 to 2016, after which the Volocopter was finally granted a provisional airworthiness certificate for its *VC200* as an ultralight aircraft in February, thus a permit to fly. The Volocopter's goal is to have its aircraft certified as an ultralight prototype which is believed to pave way for series production of the 2-seater [31].

Volocopter had its first international premiere outside Germany in Dubai in 2017 where it was tested to withstand extreme temperatures during flight. In 2019 the aircraft received an airworthiness certificate by the authorities of Finland as well. On 29 August 2019, Volocopter held a test flight at Helsinki Airport, during which it successfully integrated into both ATM and UTM systems. The test flight proved the viability of UTM systems supporting autonomous air taxi and drone operation in congested lower airspace, in combination with existing ATM systems – key step in ensuring the realization of the UAM concept [32].

So far, the most significant and the most advanced flight of Volocopter took place in Singapore on 22 October 2019. It was the first manned test flight of the aircraft and the second ever held in an urban flight setting following a test in Stuttgart in Germany. Volocopter hopes to bring commercial air taxi flights to Singapore in the near future, which made the demonstration of the ability of the aircraft to fly safely over such densely populated areas a massive achievement for the company. At the event in Singapore, the company not only held a piloted test flight, but also unveiled the first full scale *VoloPort*, a sort of a 'skyport' to serve air taxis as ground infrastructure for operation in urban areas [33].

Thus, Volocopter carried out a series of flight tests in Helsinki in cold temperatures and air with high salt contents, in Dubai in temperatures reaching 60 degrees Celsius and in Singapore with humid weather conditions. The company claims those flights provided a better understanding of how the aircraft perform in various conditions, which will contribute to future phases of development.

2.1.4 Aurora (Boeing)

From the list of UAS manufacturer examples in this thesis the company Aurora Flight Sciences is the oldest one as it has been involved in the design and construction of special-purpose UAS and aerospace vehicles since 1989. The company claims that at the core of its mission is a commitment to the science of autonomous flight, whether that means a fully autonomous drone, or a program that is breaking new ground in the interface between man and machine as it relates to flight. Since its foundation in 1989, Aurora has designed, produced, and flown around 30 unmanned air vehicles, high-altitude long-endurance aircraft, robotic co-pilots, and autonomous electric VTOL aircraft. Along its way, Aurora collaborated with Boeing on some military and commercial applications but nowadays it operates on the market as an independent subsidiary of Boeing. Among many Aurora's programs, the program called "PAV – Passenger Air Vehicle" is worth mentioning in the context of VTOL/eVTOL aircraft development and in the context of urban air mobility [34]. A visualization of the PAV is for imagery shown in Figure 4:

Figure 4 – Visualization of one of the test versions of Aurora's Passenger Air Vehicle [34]

According to Aurora, PAV is an eVTOL aircraft or air taxi which represents the next generation of autonomous electric aircraft that are safer, quieter, and cleaner. The PAV prototype should provide a solution to the transportation challenges of the future while integrating into today's current transportation systems. The aircraft should be able to autonomously transport passengers, plan routes, respond to contingencies, and detect and avoid unexpected obstacles. To navigate complex and busy urban environments, the aircraft is designed to operate with a vertiport *(skyport, n.b.)* system which will safely and quickly board and exit passengers. It aims to bring flight closer to its potential customers by providing safe on-demand transportation to minimize long commutes due to heavy congestion and urbanization in populated areas [34].

Regarding technical features, Aurora Flight Sciences is currently *(December 2019, n.b.)* developing two- and four-passenger, non-crew variants of PAV with cargo options and they are both to be fully electrically powered, autonomous from take-off to landing, and designed for urban commutes with ranges up to 50 miles (ca. 80 km). PAV, as mentioned, is an all-electric VTOL aircraft with eight propellers generating lift for vertical flight, a tail mounted five-bladed pusher propeller for forward flight and a three-surface wing configuration for cruising. The cruise speed of PAV is 180 km/h, maximum payload is 225 kg and MTOW is 800 kg [34,35].

The first flight of the full-scale PAV took place on 22 January 2019 in Virginia, where hovering and a transition to forward flight with aerodynamic lift through the wings were tested. It is important to mention that on 4 June 2019, during its fifth flight, the PAV, which was uncrewed and remotely piloted, crashed on landing on runway 34L at the Manassas Regional Airport in Virginia. According to the NTSB report, Aurora Flight Sciences was flying a pre-planned low speed flight stability test including side-to-side and forward flight maneuvers with the pusher propeller off. The pilots then noticed “brief data dropouts and abnormal motor speeds” and decided to end the flight. The pilot followed normal operation procedures by entering the Autoland function and shortly after the start of a normal descent, all electric motors stopped, and the aircraft crash landed. The NTSB found that the cause of the crash might have been airframe vibration that transmitted through the structure into the flight controller. Then the accelerations resulting from the vibration briefly exceeded the jerk logic threshold which made the aircraft enter the ground mode and subsequently command the motors to shut down. Aurora intends to resume flying with its second prototype in 2020 [35].

PAV test models are currently certified to the certification specification FAA 14 Code of Federal Regulations (CFR) Part 21.195 – Experimental certificates: Aircraft to be used for market surveys, sales demonstrations, and customer crew training. For later normal operation, PAV is to be certified in the USA to the specification FAA 14 CFR Part 23 – Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes.

2.1.5 Vahana (Airbus)

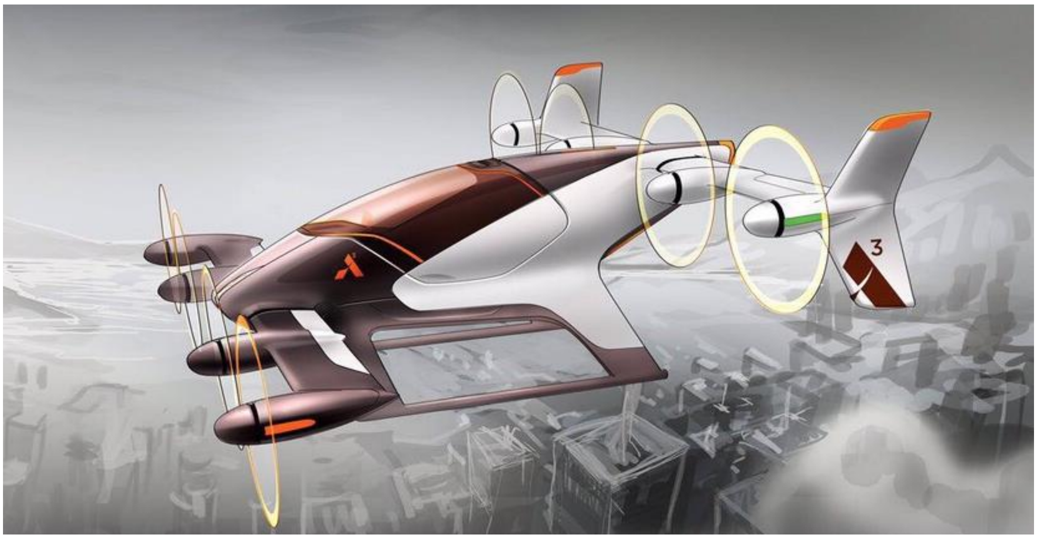

Figure 5 – Visualization of the Vahana vehicle [17]

The Airbus Vahana (Airbus A³ Vahana – *pronounced "Airbus A-cubed Vahana", n.b.*) is an electric-powered eight-propeller vertical take-off and landing aircraft financed and developed by A³ by Airbus and Airbus Urban Mobility. The project started in 2016 in Silicon Valley as "a sketch on a napkin" and made it to a full-scale flying aircraft in less than two years. In 2017 small-scale models were flown to test out the Vahana Concept in California. The full-scale aircraft *Alpha* made its maiden flight on 31 January 2018. By January 2019, the second aircraft *Alpha 2* was completed, while the first aircraft was testing a transition to forward flight, which was eventually achieved on 3 May 2019 on its 58th flight [36].

Vahana uses eight electric motors and a tandem tilt-wing configuration that converts between rotor-borne vertical and wing-borne forward flight. This configuration enables Vahana to achieve both vertical take-off and landing as well as cross-city flight range on battery power alone. Its cruise speed is 100 kn (190 km/h), enabling trip times that are two to four times faster than cars. The vehicle is self-piloted, which is enabled by its onboard detect-and-avoid systems that can identify both air and ground hazards. Airbus claims that the range of the aircraft is 50 km enabling connections within cities as well as urban and suburban connections, and that it is quiet, producing less noise than a traditional helicopter [37].

The aircraft aims to carry one passenger or cargo and be fully autonomous. Compared to other similar projects, the biggest disadvantage is to be found precisely in capacity of the aircraft, as the other vehicles have a capacity of at least 2 passengers. However, a two-seat version of the next model *Beta* with higher cruise speed and greater maximum payload is also planned for the future. The Vahana's goal is to be utilized specifically as a single/double seated autonomous air taxi for urban mobility which will follow predetermined flight paths making minor deviations should obstacle avoidance be necessary [38]. The Table 3 below shows some technical specifications of Vahana.

Vahana as a VTOL aircraft does not need a runway for take-offs and landings as these maneuvers are performed from a single place. Nevertheless, in order to maintain safety and operation as a real air taxi, not just a prototype, the necessary infrastructure in the form of skyports has to be built so that it will allow the aircraft, by its parameters, to operate safely in both densely populated and sparsely populated areas.

Table 3 – Technical specifications of Vahana [38]

Version	Alpha	Beta
Capacity	1 (unmanned)	2
Fuselage length	5,7 m	5,86 m
Overall height	2,81 m	2,81 m
Wingspan	6,25 m	6,25 m
Empty weight	475 kg	475 kg
MTOM	815 kg	815 kg
Maximum payload	90 kg	200 kg
Range with reserves	60 km	100 km
Altitude	1'524 m	3'048 m
Cruise speed	110 kn (200 km/h)	125 kn (230 km/h)
Propulsors	8 propellers	8 propellers
Power supply	electric/batteries	electric/batteries

2.1.6 Primoco UAV

Figure 6 – Primoco Unmanned Aerial Vehicle [39]

Primoco UAV is a medium-sized UA, designed and manufactured by a Czech company Primoco UAV SE which produces two versions of the aircraft – One 100 and One 150. It is primarily intended for civilian and government applications of air operations. Civilian applications include:

- intelligence-based agriculture that uses real time provision of data and images;

- remote mapping by means of a 3D LIDAR scanner[1];
- LIDAR for power line corridor mapping within infrastructure management;
- mining support and mapping;
- disaster response and environmental management etc.

The government applications of Primoco UAV include:

- security and intelligence;
- coastal surveillance;
- search and rescue; and
- border protection by means of video and thermal information support package.

The UA is claimed to be built to be reliable allowing both daylight and night operation with a capability to withstand poor weather conditions. It can be operated by a remote control during each phase of flight, but additionally, the integrated auto-pilot system enables fully automatic take-off, landing and fully autonomous flight plan execution based on pre-programmed waypoints. It also has additional safety modes which allow it to return to base or land in a safe area if communication is lost or faults occur. The UA needs a runway length of 300 meters, thus providing executions of aerial missions also from remote locations with limited airport facilities. Mode S Transponder, the aircraft is equipped with, also allows to integrate the flight path of the aircraft into normal civilian airspace without special authorization [39].

Primoco piston Engine 250/340 using unleaded 95 octane gasoline powers the UA by actuating a pusher propeller located at the rear of the UA's fuselage. The engine is further equipped with a twin-spark ignition system which improves reliability and flight safety by ensuring that even a partial failure of the electrical system will not stop the engine from functioning. A fixed wing construction of the aircraft provides extended range and reliability in adverse weather conditions. Technical specifications of Primoco UAV (One 150 version) are shown in the Table 4 below.

The first flight of the aircraft took place in July 2015 and the UAV Model One 100 started full production in January 2016. Primoco UAV SE claims to already have produced 50 aircraft as of February 2020 and also has its own research and development team, complete production equipment and trained staff capable of producing up to 50 UAs per year. In the medium term by 2023, the company plans to produce up to 250 UAs annually in the Czech Republic for the world market, primarily to monitor strategic infrastructure, border control and other civilian missions [39].

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[1] LIDAR *(Light Detection and Ranging)* – surveying method that measures distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor [40]

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Table 4 – Technical specifications of Primoco UAV [39]

Wingspan	4,85 m
Length	3,65 m
Height	1,25 m
Maximum take-off weight	150 kg
Payload	1 – 30 kg
Maximum range from a ground control system	200 km
Maximum distance	2 000 km
Cruising speed	100 – 180 km/h
Flight endurance	15 hours
Maximum altitude	3 300 m
Runway length	300 m
Navigation system	GPS / Glonass / Galileo / Beidou
Air traffic control	Transponder Mode S
Communication	Radio Datalink, Satellite Communication Inmarsat
Equipment	Lidar sensor Multispectral / Hyperspectral camera / Customized sensors / payload as required

3 Operational risks of UAS

3.1 Need for legislative regulation

Aviation as a mode of transport is generally one of the most legislatively regulated sectors. Aviation legislation is issued at a national and an international level. At the national level, the aviation is regulated by local aviation/transport authorities, which issue various decrees and implementing regulations for international legislation to fit into legislative frameworks of individual countries. In the territory of the European Union, air transport authorities were associated in the organization called Joint Aviation Authorities (JAA) until 2008 when it was fully replaced by the European Union Aviation Safety Agency – EASA – which took over all the responsibilities and functionalities of JAA. At the transnational level, the International Civil Aviation Organization (ICAO) is active in issuing rules applicable to all ICAO Member States, of which there are 193 in 2020. With the exception of various territorial disputes and political nuances, it can be stated that ICAO is legislatively covering air transport worldwide. There are many good reasons to regulate air travel at several levels. All in all, the standardization of aviation, weather in terms of its operation, aircraft certification and design, or production and maintenance, has enabled this mode of transport to grow globally. Aviation standardization has allowed air transport operations to adopt uniform rules in all parts of the world, regardless of political situation, economic prosperity, or local cultural conventions. Today, air transport is an important worldwide unified transport mode and an important economic sector of the world's economy, creating many jobs primarily, as it employs many people and companies, and secondarily allowing many other sectors to thrive by creating jobs in manufacturing, security, computer science, tourism and many other fields. For these reasons, it is essential for air transport as a whole to be safe, efficient, sustainable, and globally as uniform as possible. These required characteristics of air transport can only be supported by the legislative frameworks of states and multinational groupings of states that are authorized to issue legislation and supervise its application in practice.

As mentioned above, nowadays, virtually every area of aviation is legally regulated, from aircraft design and production, through operation (airports and heliports, airlines, ground handling of aircraft and passengers, traffic safety, air traffic management, etc.) to aircraft maintenance. This comprehensive legislation has undergone many years of development, which has always reflected the current needs of a particular area. Urban air transport and mobility is a relatively new area of air transport ant it is likely to evolve into a self-functioning transport mode in the coming years. If this mode of transport is to be developed into full functionality and day-to-day operations, there is a natural need to regulate it in exactly the same way as in commercial or general aviation since the risk of its operation is comparable to standard manned operations. Today, numerous studies and empirical findings have shown that even relatively small drones pose a huge threat to aviation in case of being used recklessly, whether in terms of safety in an event of a collision or in terms of security regarding personal privacy and data protection. Therefore, UAS operators, as well as UAS aircraft themselves, must be subject to registration and certification, and competent authorities should be aware of them and their operations. Regarding privacy, data and personality protection, unmanned aircraft systems are particularly required to be regulated in case they are capable of collecting data or recording videos, using various sensors and cameras, which can not only endanger privacy of people, but also pose a security threat to a state.

In the case of UASs operating in the 'certified' category, the need for regulation is all the more obvious. According to the European UAS-related regulations ([10,11,12]), the design, production, and maintenance of UAS must be subject to regulation when their characteristic dimension is 3 meters or more, when they are designed to operate above assemblies of people, and when they are designed for transporting people or dangerous goods, in order to mitigate the risk to third parties in the event of an accident. The operation of drones within the urban air mobility concept will require the pilot to have perfect maneuverability as they will mostly be operated above densely populated areas in congested airspaces above cities and they will take off and land at skyports located on or in close proximity to buildings and other urban transport infrastructure. Proposed regulations have to ensure adequate protection of buildings, road and rail users, and non-motorized users such as pedestrians and cyclists. Regulations will have to continue ensuring the collision avoidance with commercial and general aviation traffic, but also consider the adverse environmental impacts on the population in terms of excessive noise and impacts on nature as well. Given the intended green, electric propulsion of eVTOLs, exhaust emissions and the resulting carbon footprint will not be a major issue. The legislation, however, must pay particular attention to reducing the impact on the fauna concerned, especially birds, which themselves pose a threat to aircraft in case of a bird strike.

3.2 Legal aspect of autonomous operation

The most problematic facet of regulating the operation of UAS in the 'certified' category remains the legal liability for third party damage, property loss, or loss of life caused in the event of an accident of a UAS operated in full autonomous fashion. Legislative mechanisms must be in place to create a sort of liability axis, at the end of which the entity will be liable in the event of an accident caused by an autonomously operated aircraft. Such a legal mechanism would have to consider the safeguards established by the manufacturer of the autonomous UAS, alternatively the supplier of artificial intelligence software. With regard to the safeguards given by these entities, the set of potentially liable entities could be narrowed. Particularly problematic seems to be the transfer of liability to the owner or operator of a UAS, who would not be able to shape the course of the flight by its own activity and could not therefore take any degree of fault for a potential accident. In this case, either the manufacturer or the artificial intelligence software supplier would be responsible for the accident. Here too, however, the problem arises if an accident would happen in response to a fact that could not have been foreseen even with full caution. This could be caused by force majeure, or the so-called *vis major*, which would mainly be of natural origin – severe weather conditions such as tornados and hurricanes, or network blackout caused by excessive solar activity, etc.

It is questionable to what extent aircraft manufacturers and artificial intelligence software suppliers would be willing and able to guarantee their full autonomous functionality, and to what extent the owners and operators of autonomous UASs would accept these safeguards. From a legal point of view, the introduction of fully autonomous operation has many challenges to address and resolve. These challenges, considering previously mentioned issues, include the applicability of uniform rules to the legal frameworks of individual countries, i.e. the standardization of the legal framework related to the autonomous operation of UAS at the EU and international (ICAO) level. The establishment and feasibility of introducing such legal mechanisms should be subject to further analysis and research and may be the topic of future academic works.

3.3 UA test sites

The safe operation of eVTOLs is preceded by a long-term development of UAS, which is inherently linked to numerous test flights. Test flights usually take place at designated airports whose purpose is obvious. In order to enable the manufacturer to operate his equipment and maintain the prescribed level of safety, a number of test flights involving various activities prescribed by the relevant legislation must be carried out to verify the performance characteristics of the aircraft. Test flights at selected airports take place in a reserved or a segregated airspace whose dimensions must be appropriate to the nature of the most frequently performed test. In terms of traffic noise limits, testing sites are subject to generally applicable legislation based on ICAO Annex 16 – Environmental Protection, which is adapted to suit local conditions.

In the Czech Republic, number of airports are used to perform test flights (such as the already mentioned Primoco project, which uses the airport in Písek for testing or another Czech project, ZURI, which uses the airport in Milovice and which is described in more detail in the Appendix I to the thesis). Active testing of unmanned aerial vehicles is also carried out by the Czech Army in military areas and their respective airspaces [41].

Within the European Union, EASA sets out, through certification specifications (in the case of the UAS in question, document CS-23 for now) a detailed testing manual with all required activities. The safety requirements for the test sites intended for the testing of experimental aircraft shall be established at the level of individual Member States. Test flights in the Czech Republic are carried out in accordance with §15 of the Civil Aviation Act No. 49/1997 Coll. as amended. The implementing regulation for test flying is the Directive for test flights of civil aircraft CAA-TI-010-n/99 issued by the Civil Aviation Authority of the Czech Republic. This Directive defines a test flight as *"any flight during which the airworthiness of an aircraft or its systems is verified or used for research and development purposes. Test flights are performed by legal or natural persons who are authorized to develop, design, manufacture, test, maintain, make modifications, or design changes".*

Aircraft developed in the world and in the Czech Republic within the concept of urban air mobility, according to the Directive, belong to the category "test flights of prototypes and experimentally modified aircraft" since such flights are used for research and development purposes. For the sake of completeness of information, the Directive also defines three additional categories of test flights – test flights of serial aircraft, operational test flights, and test flights performed within the random airworthiness review of aircraft registered in the Aviation Register of the Czech Republic. The test flights are performed by fully medically and professionally qualified persons who are holders of a valid authorization to conduct test flights of the relevant aircraft type. These persons are authorized by the CAA. The qualification requirements are defined in more detail in points 2.1 and 2.2 of the Directive. The process of conducting and granting a permit to conduct a test flight, including the relevant application forms, is set out in more detail in the subsections of the section 4. Section 5, in turn, deals with the orders, protocols and methodology of test flights. [42].

From a safety point of view, in order to prevent collisions, it is allowed to carry out test flights exclusively in designated airspace. An overview with information on airspace activation in the Czech Republic is published in the most user-friendly way via the official Air Navigation Services of the Czech Republic (ANS CR) application – *AisView.rlp.cz*. The application shows the activation of managed airspaces, active TSA and TRA airspaces, restricted and dangerous areas, etc. together with warnings and meteorological information. For entities interested in UAS testing, ANS CR shares information on airspace activation and usability through the official application – *dronview.rlp.cz*, where it is possible to directly find the conditions of UAS operation related to individual airspaces. The altitude limits of the airspace, information on the need for a permission from the CAA to perform a UAS flight and other instructions, conditions and recommendations concerning the operation of the UAS are given as well. To protect ground personnel and public during the course of a test flight, protection safety zones shall be established with prohibited or restricted access by persons defined by the Civil Aviation Authority. Test performers shall also follow the safety guidelines of test site operators, the VFR Manual under Title 4 of Regulation L2 or the Airport Rules of the specific test site.

For comparison, in the United States, test flights for experimental aircraft and test sites are dealt with in regulations issued by the FAA, specifically Title 14 of CFR – Aeronautics and Space and its Part 91, which lists:

- § 91.305 – Flight Test Areas; and
- § 91.319 – Aircraft having experimental certificates: Operating limitations.

According to this legislation, an unproven experimental aircraft must be assigned to an experimental flight test area located over open water, or sparsely populated areas. For compliance with the established requirements and with regard to safety in terms of protection of persons and property, the FAA must evaluate each test site assignment application to determine that the area for testing is designated in a reasonable way to accomplish the testing program. All initial flight operations conducted in a test must be limited to the assigned test site until the aircraft is proven to be controllable throughout its normal range of speeds and maneuvers without displaying any hazardous operating characteristics. If the assigned test site is close to a densely populated area, a flight corridor subjecting the least number of persons and property exposed to possible hazards must be ensured. The corridor is then used for leaving the test site and all activities included in the test program must be performed in a remote location with the possibility of returning to the site using exclusively the established corridor. Experimental aircraft are assessed individually with respect to the type and complexity of the aircraft. The operating limitations are amended by the FAA once the applicant certifies and compliance with Part 91 is found [43].

4 Air Traffic Management Services for Unmanned Aerial Systems

An important part of UAS operations is their integration into the air traffic management (ATM) system. This chapter describes the integration of UAS into the ATM system from a global and especially European transnational perspective, which describes the activities within the Single European Sky initiative with the creation of U-space airspace and from the perspective of local Air Navigation Services of the Czech Republic. As described further below, current activities in the field of unmanned traffic integration focus mainly on the 'open' and 'specific' operating categories of UAS, while the 'certified' category is still only a marginal issue. For this reason, the chapter also incorporates a view that is largely based on the concept of operation in urban air mobility environment, presented by the company Embraer in its *White Plan of Air Traffic Management for UAM* (hereinafter referred to as the *White Plan*). At the same time, it is appropriate to look at U-space as the desired future real state, while the concept presented by the *White Plan* is only an idea, which, however, can partially represent an inspiration for future improvements of the U-Space system.

4.1 Single European Sky

The Single European Sky (SES) is an initiative of the EU launched by the European Commission in 2004 to reform the architecture of European ATM intending to improve performance of air traffic management and air navigation services through better integration of the European airspace. SES objectives include harmonization and improved efficiency in ANS provision across the European Union, reducing the fragmentation of the European airspace, reducing delays, increasing safety standards and flight efficiency, and improving the integration of military systems into the European ATM system. In practice, the SES should result in reduced flight times due to shorter paths and fewer delays and, consequently, in lower flight costs and aircraft emissions which will mitigate the environmental footprint of aviation. Other significant benefits of the SES shall be [44]:

- an improved level of safety of air navigation services,
- a more effective and integrated air traffic management architecture,
- demand-driven air navigation service provision,
- enhanced cross-border coordination, and
- improved decision making and enhanced enforcement in ATM.

Europe’s airspace is currently fragmented and divided along national borders which often leads to duplication of effort and inefficiencies as airspace users must often times fly further than they need to, increasing fuel burn and CO_2 emissions. The SES, on the other hand, represents a concept of separate airspace blocks called ‘functional airspace blocks’ or FABs. These blocks are intended to remedy the fragmentation of the European airspace by restructuring it according to real traffic flows rather than national boundaries. The current airspace division will cease to exist and new FABs will be created by merging a larger number of current blocks of airspace into a smaller number of functional blocks. In each FAB, the member states concerned must jointly designate one or more air traffic service providers within whose competence air traffic control in that particular area will fall. One of the most important and core initiatives, when it comes to Single European Sky, is a Single European Sky ATM Research Program also called SESAR, which is described in the following subchapter.

4.1.1 SESAR

Single European Sky ATM Research (SESAR) refers to the technological pillar of the Single European Sky which arms to improve European air traffic management performance by modernizing and harmonizing ATM systems through the definition, development, validation and deployment of innovative technological and operational ATM solutions [45,46].

SESAR's vision builds on the notion of trajectory-based operations and relies on the provision of air navigation services in support of the execution of the business or mission trajectory, meaning that aircraft can fly their preferred trajectories without being constrained by airspace configurations. This vision is enabled by a progressive increase of the level of automation support, the implementation of virtualization technologies as well as the use of standardized and interoperable systems. The system infrastructure will gradually evolve with digitalization technology, allowing air navigation service providers, irrespective of national borders, to plug in their operations where needed, supported by a range of information services. Airports will be fully integrated into the ATM network level, facilitating, and optimizing airspace user operations [46]. The objectives of the SESAR initiative with respect to the phases of flight are shown in Figure 7:

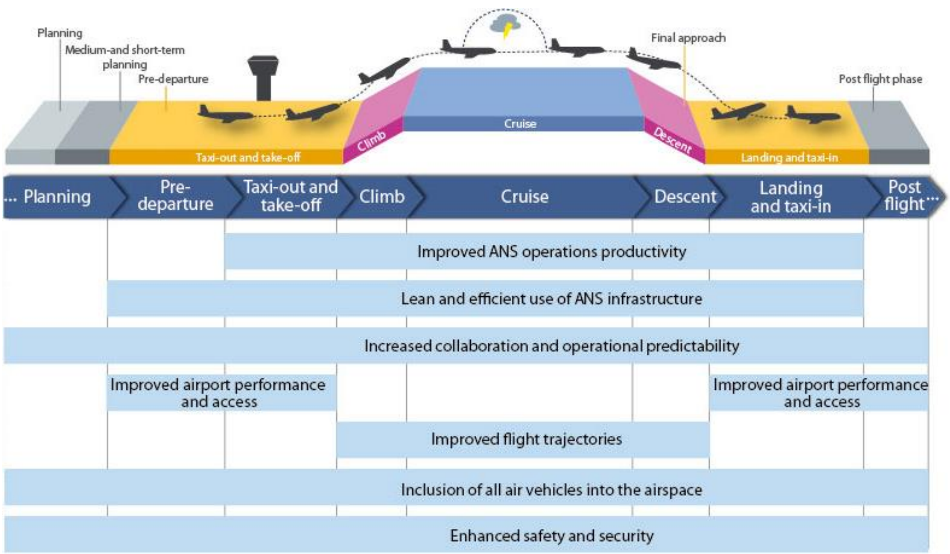

Figure 7 – SESAR objectives throughout the phases of flight [44]

The SESAR program is largely co-financed by EU funds and comprises the three following phases, the last two of which are currently underway simultaneously [46,47]:

1. **definition phase** (2005 – 2008) that has produced the ATM master plan identifying the technological steps and the modernization priorities necessary for implementing a new ATM concept, the phase is already completed;
2. **development phase** (2008 – 2020+), managed by the SESAR Joint Undertaking[2], focused on research and development of new technologies and processes in ATM to ensure the replacement of the existing ground and airborne systems and interoperability with those outside Europe;
3. **deployment phase** (2014 – 2020+), managed by SESAR Deployment Manager[3], dealing with implementation of the new ATM infrastructure and of the corresponding aircraft equipment.

4.1.2 U-space

In 2017, SESAR Joint Undertaking issued the document called *U-space Blueprint* that sets out the vision for U-space as a set of new services and specific procedures designed to support safe, efficient and secure access to airspace for a large number of drones. These services should rely on a high level of digitalization and automation of functions, whether located on board the drone itself, or part of the ground-based environment. U-space should provide an enabling framework to support routine drone operations, as well as a clear and effective interface to manned aviation, ATM/ANS service providers and authorities. Thus, it should not be considered as a defined volume of airspace segregated and designated for the sole use of drones, but rather as an ecosystem that will ensure the smooth operation of drones in all operating environments and all types of airspace. The key principles defined by the Blueprint and on which the U-space architecture is to be built are as follows [48]:

- to ensure the safety of all airspace users operating in the U-space framework, as well as people on the ground;
- to provide a scalable, flexible, and adaptable system that can respond to changes in demand, volume, technology, business models and applications, while managing the interface with manned aviation;
- to enable high-density operations with multiple automated drones under supervision of fleet operators;

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[2] SESAR Joint Undertaking – a public-private partnership responsible for the coordination and concentration of all European Union (EU) research and development activities in ATM as part of the SESAR program.

[3] SESAR Deployment Manager (DM) – a body nominated by the European Commission to coordinate and synchronize the Deployment Program which aims at implementing SESAR targets.

- to guarantee equitable and fair access to airspace for all users
- to enable competitive and cost-effective service provision at all times, supporting the business models of drone operators
- to minimize deployment and operating costs by leveraging existing aeronautical services and infrastructure, including GNSS, as well as those form other sectors, such as mobile communication services;
- to accelerate deployment by adopting technologies and standards from other sectors where they meet the needs of U-space;
- to follow a risk-based and performance-driven approach when setting up appropriate requirements for safety, security, and resilience, while minimizing environmental impact and respecting the privacy of citizens, including data protection.

Another important document that SESAR Joint Undertaking published in 2019 and that builds on the principles defined in the Blueprint, is the document *Initial view on Principles for the U-space architecture*. As the title implies, the aim of the document is to provide principles that will guide U-space projects in their implementation and that will support U-space implementers by establishing a common approach to defining and implementing U-space. The architecture of U-space must be such as to allow multiple U-space providers to operate in the same volume of airspace at the same moment by ensuring that all the providers have exactly the same situational awareness and the traffic is de-conflicted and safe. For this to happen, it will be essential to establish cooperation and exchange of data between the various service providers. The following Table 5 shows in general the actors and stakeholders involved in U-space implementation and how they should act in the U-space context [49]:

Table 5 – Stakeholders involved in U-space implementation [49]

Stakeholder	Role
Authorities	
Civil Aviation Authority	The main authority, which governs the airspace for the given geographical region. There is one unique certified airspace authority in a given region.
Military Authority	The main authority empowered to make decision on military matters on behalf of its state and managing part of the airspace in a given region.
Local Authorities	The optional additional authorities that manage part of the airspace in a given region or has some privileged roles permissions (e.g. cities, law enforcement, airports, local harbors, emergency services).
	Provide unique data that feed the U-space services; for example, complementing the AIM data for low level airspace. The local authority operates at the mandate of the regulating authority, which is the Civil Aviation Authority.
	The Local authority may be delegated this role in some locations and hence there may be a Local authority which replaces or supplements the Civil Aviation Authority in that location. The Local authority may include U-space data consumers such as law enforcement bodies,

Stakeholder	Role
	emergency services (for example the creation of no-drone zones during emergency responses).
Other authorities	Registrar, airworthiness authority, radio technical compliance and similar authorities will support various U-space services, either directly or through delegated entities.
Service Providers	
Air Navigation Service Provider	Provides situational awareness information about the traffic they are responsible for.
Aeronautical Information Management Providers	Existing ATM provides sources of some data consumed by U-space service providers and users
	ANSPs are also consumer of U-space data.
Common Information Service Provider	The potential entity (option) that might provide some safety or security and data privacy critical services should the need arise for unique services (e.g. registration, identification, geo-awareness, interface with ATM).
U-space Service Providers (USSPs)	The entity that provides U-space service access to drone operators, to pilots and/or to drones, to other operators visiting non-controlled very-low-level airspace.
	Multiple services could be provided by different U-space Service Providers.
Supplemental Data Service Provider	An entity that provides access to supplemental data like terrain, weather, cellular coverage.
	Multiple services could be provided by different Supplemental Data Service Providers.
Drone Operator	
The Operator is the legal or natural person operating one or more unmanned aircraft. The drone pilot is a role of the drone operator. A drone operator can operate a drone using one or a combination of two piloting techniques; it can directly operate the drone as a remote pilot or use an automatic on-board pilot system.	
Remote pilot	The actor (human or machine) operating the drone.
Automatic on-board pilot	This refers to the level of automation of the drone; at the low levels of automation this could be limited to data collected by on-board sensors and sent to the USSP whereas at highest level of automation this is about piloting functions and on-board decision making with little or no human intervention.
Aviation user	The pilot of a crewed aircraft, gliders, parachutists etc.
Privileged users, law enforcement, military	There are users serving law enforcement and military who may have special access rights to information in U-space. (For example, in some cases the military will have particular duties which will make them consumers of U-space services and data.)

Based on the vision defined in the Blueprint and related principles of high-level automation, connectivity and digitalization for drones and the U-space system, the architecture of U-space has been defined to have some specific properties. It has to have a service-oriented approach to ensure that the solutions are built with common characteristics. It should be modular so that it can be decomposed in functional blocks with defined functionalities and required inputs/outputs which can be reused or replaced. 'Safety first' rule must be maintained so that the system always considers the safety of its stakeholders and other people affected by U-space operations. The system should be built with an open architecture that is component-based to make adding, upgrading, or swapping parts of the system easier during its lifetime, which will increase flexibility, reduce costs and risks, and improve interoperability. Standardization will ensure that whenever there are exchanges between roles of the stakeholders, the interfaces are defined, and related tasks of the stakeholders are clear. These and many other features of the system architecture, whose detailed description would go too deeply into the issues of system analysis, are the starting point for establishing U-space principles that ensure that the system is safe, reusable, publicly accessible and auditable (for investigation purposes if requested). It also has to be interoperable with ATC – U-space data sent to ATC has to comply to ATC requirements and has to be valid in a timeline in order to be secure and sustainable. All these requirements for U-space are detailed in the aforementioned document *Initial view on Principles for the U-space architecture.* As stated in the document itself, since the content of this document is still live, the principles stated therein will be reviewed in the light of the consolidation of the U-space projects outcomes and will be aligned to the coming EASA U-space regulation which is yet to be delivered by the end of 2020 [49].

On 13 March 2020, the draft **EASA Opinion No. 1/2020** was published. Its objective is to create and harmonize the necessary conditions for manned and unmanned aircraft to operate safely in the U-space airspace, to prevent collisions between aircraft and to mitigate the air and ground risks. It was a first regulatory step to allow immediate implementation of the U-space after the entry into force of the Regulation and to let the unmanned aircraft systems and U-space technologies evolve. It describes the structure of rules defined by individual articles imposing requirements on building blocks of the U-space system. Aspects of the U-space system that need to be mentioned in terms of the elaboration of this thesis are described in more detail in the following subchapters as they are presented in the EASA Opinion.

4.1.2.1 U-space designation

The aforementioned Opinion states that the Member States have full authority on the designation of the U-space airspace, and that they decide how their airspace is designed, accessed, or restricted. The U-space airspace can be established in either controlled or uncontrolled airspace. Air traffic service providers are designed to provide air traffic control services in controlled airspace and flight information service providers provide a flight information service and an alerting service in many parts of uncontrolled airspace. When designating U-space airspace and integrating USSPs to provide U-space services to UAS within controlled and uncontrolled airspace, the already established principles need to be considered and respected. Both ANSPs and USSPs are certified to provide their respective services in a safe, secure, and continuous manner. Within controlled airspace, U-space airspace is designed by the Member States and is dynamically managed by the ANSP. The safety of operations is guaranteed by manned and unmanned traffic not mixing with each other as they are dynamically segregated and ANS and U-space services are not provided at the same time in the same volume of airspace [50].

In uncontrolled airspace, the airspace remains uncontrolled for manned aircraft. However, when the MS designates a volume of airspace as U-space airspace, UAS operators are required to use the U-space services to fly in that airspace, and manned aircraft operators are required to make available their position to the USSPs at regular intervals. In order to ensure there is no conflict between both types of operations, the relevant information concerning position and possible trajectories has to be shared mutually [50].

4.1.2.2 UA Operator requirements

The Opinion further states general requirements for aircraft operators and USSPs, which are based on the assumption that UAS operators share the airspace with manned aircraft. At a strategic level, the UA operator has to establish a contract with one certified USSP providing the mandatory set of U-space services in the airspaces the UA operators intend to use. At pre-tactical level, UA operators submit a flight authorization request form to the contracted USSP in accordance with the terms and conditions of the flight authorization once it is granted by the USSP. A flight cannot be commenced until the flight authorization has been granted by the USSP. If UA operators are unable to comply with the terms and conditions given by the USSP in the granted flight authorization, the original flight authorization request has to be amended. UA operators are also required to comply with the instructions of the USSP, as well as ensure that their UA are technically capable of receiving the U-space services and of operating in the U-space airspace [50].

Requirements and obligations are also placed on operators of manned aircraft operating in U-space airspace that is designated in uncontrolled airspace, and for uncontrolled traffic within controlled airspace such as VFR traffic in class E. In order to allow the USSPs to safely manage the unmanned aircraft in such U-space airspace and provide the UA operator with manned traffic information, they need to know where the manned aircraft will be in the U-space airspace in order to be able to mitigate air risks. Therefore, manned aircraft operators will need to provide information about their position at regular intervals, with the necessary level of performance in terms of integrity, accuracy, continuity and availability as well as security to allow the USSPs to make use of this data for the provision of U-space services [50].

4.1.2.3 U-space Service Providers

A U-space Service Provider shall be a new entity created by the regulation proposed with the Opinion No. 1/2020. Its Article 8 sets requirements placed on USSPs in order to ensure that they can provide services to support safe and efficient movement of aircraft in the U-space airspace. A USSP is an organization certified by the relevant competent authority to provide U-space services in U-space airspace to UA operators or to other USSPs. A USSP must be capable of providing at least the four mandatory U-space services – network identification, geo-awareness, traffic information and UAS flight authorization, which are described more in detail further in the text. USSPs can be joint in a form of an association or an equivalent mechanism as long as it is clear that there is a single entity responsible for providing the minimum set of services towards the UA operators. In the context of the flight authorization management, USSPs are required, with regard to the flight authorization request of the UA operators, to check for its completeness, plausibility and accuracy, and, accordingly, accept or dismiss it, and notify the UA operator. The information needed for this process such as airspace restrictions, traffic information, etc., will be available from the CIS and exchanged with ANSPs when necessary. USSPs will need to be properly certified, but as organizations they will be able to provide U-space services in any U-space airspace within the European Union. This means that the USSP does not necessarily have to be designated for only one airspace [50].

In the foreseeable future, the Opinion does not consider that USSPs would provide ATC-like services in controlled airspace such as aircraft separation and collision avoidance since in the beginning, they are not designed to meet the same certification requirements as ATS providers. EASA, however, claims to review the applicable regulations once U-space services are matured, developed, and validated. In uncontrolled airspaces, USSPs shall provide services to UA operators. Nevertheless, as the airspace remains uncontrolled for manned flights, USSPs must provide pilots of the manned aircraft with information on where U-space airspace is established with the view to resolving potential conflicts and ultimately avoiding collisions [50].

4.1.2.4 U-space Services

As mentioned above, four mandatory services are proposed to function within U-space airspace – network identification, geo-awareness, traffic information and UAS flight authorization. The aim of the U-space services is to:

- prevent collisions between UAS and manned aircraft and between UAS themselves;
- maintain an orderly flow of UAS traffic;
- provide information and instructions relevant for the safe and efficient conduct of UAS operations;
- notify appropriate organizations regarding emergency or abnormal situations when people and goods on the ground or manned aviation are endangered; and
- ensure that environmental, security and privacy requirements are met in the Member States.

The way U-space services are designed and implemented has to be harmonized in order to avoid having different requirements on UAS equipment and capabilities across the EU countries. UA operators will need to be able to receive the same services, thus, to have the same interfaces with USSPs to operate in all U-space airspaces across the EU. The list of U-space services as proposed by the EASA Opinion is presented in the following Table 6 together with descriptions of the individual services.

Table 6 – U-space Services proposed by EASA [50]

	U-space Service	Role description	Distributed content
Mandatory Services	**Network Identification**	Continuous processing of the remote identification of UAS throughout the whole duration of the flight and providing the information to authorized users. USSPs have to be able to receive and exchange broadcast.	UAS operator registration number, geographical position of UAS and its height above the surface or take-off point, route course (heading) and ground speed, emergency status, message generation time
Mandatory Services	**Geo-awareness**	Based on the risk assessment, MS may prohibit certain UAS operations, request particular conditions for certain UAS operations in terms of aircraft equipment or a prior operational authorization. UAS operations may be subject to specified environmental standards and access to certain airspaces may be allowed only to UAS with particular remote identification system or other technical equipment.	– Data containing information on airspace limitations related to UAS position and altitude imposed by geographical zones (geometry of airspaces). These shall be updated in a timely manner to address contingencies and emergencies. – Update times, version numbers and time validity. – Warning alerts to the pilot when a potential breach of airspace limitations is detected. – Information to the pilot un UAS's status and warning alerts in case positioning or navigation systems do not operate properly.
Mandatory Services	**Traffic Information**	Alerting and helping UAS operators to avoid collisions by providing information on other known or observed air traffic in close proximity to the position or intended route of the UAS. Provision of the service is enabled to a USSP through the Network Identification System or other technical means, e.g. manned aircraft ADS-B, transponders, etc., implementer in the U-space airspace. Upon receiving the traffic information services from the U-space service provider, UAS operators take relevant actions to avoid collision hazard.	– Real time 3-D position of the known air traffic – manned or unmanned aircraft; – 3-D position includes: latitude, longitude, altitude, and time of report; – speed, heading or direction, and emergency status, if known; Traffic information is updated at a frequency that the competent authority has determined to be adequate for safety in the given U-space airspace.
Mandatory Services	**Flight Authorization**	Providing authorization to UAS operator to enter the U-space under the terms and conditions specified by the USSP. Checking flight authorization requests against airspace restrictions and limitations maintained within the Geo-awareness Service. Ensuring strategic de-confliction from other air traffic. The service is mandatory in both controlled and uncontrolled airspace and applies to UAS operators in order to maintain the situational awareness of USSPs of all UAS traffic intending to operate in the U-space airspace.	– Flight authorization request UAS operators need to fill in prior to departure; – Unique authorization number associated with each flight authorization to enable identification of the USSP issuing the authorization. When granting a flight authorization to a UAS operator, priority rules are to be respected in accordance with aircraft status, whether it is a manned or unmanned operation, there are passengers on board or not, etc.
Supporting Services	**Tracking**	Supporting the mandatory services used for example for tracking real-time historical telemetry data of the UAS if necessary infrastructure exists. Providers of such service can track UAS through the signal between the aircraft and its remote controller as well as additional surveillance observations. Telemetry messages are comprised with actual information from the UAS, flight plans, and identification information in order to calculate UAS flight tracks, including positions, headings, and speeds.	A tracking report shall contain: identities of UAS, operators, and mission plans, an identifier of the system that has calculated the track, the time of track position calculation, a 3-D position of UAS at the calculated time, a route course and a ground speed, and estimated uncertainties of calculated positions, courses and ground speeds of UAS. Track updates are produced in determined appropriate time frequencies, approved methods are used for identifying and fusing tracks collected from different sources representing the same unmanned aircraft, track reports of uncorrelated tracks are provided, record of all available surveillance and data sources are kept, alerts of outages or of degradation of service are generated, and logs of all tracks and alerts shall be retained for certain time periods for investigation purposes if necessary.

U-space Service	Role description	Distributed content
Weather Information	Collecting weather information necessary to support UAS operational decisions and the provision of other U-space services such as the Flight Authorization Service. Providing UAS operators with forecast and actual weather information either before or during flight and making available weather information provided by trusted sources. Weather information for UAS operations may be different from the one provided by today's meteorological service providers in order to better adapt to the operational requirements of the UAS which will be operated in closer proximities to buildings and in areas where current meteorological information is not provided. The possibility that current aeronautical meteorological service providers can also provide this service is not excluded.	Minimum content of weather information for the purpose of UAS operations: – wind direction clockwise through the true north; – wind speed in meters per second, including gusts; – height of the lowest broken or overcast layer in hundreds of feet above ground level; – visibility in meters and kilometers; – temperature and dew point; and – indicators of convective activity and precipitation. The weather information has to be sufficiently reliable to support operational decision-making, and has to include the location and time of the observation, or the valid times and locations of the forecast.
Conformance Monitoring	Monitoring whether UAS operators comply with requirements and information provided in the UAS flight authorization request. Alerting UA operators when the flight authorization deviation thresholds are to be violated and when requirements are not complied with. The service checks the current track of each UA with respect to its planned mission as defined in the approved flight authorization, considering the existence of new geo-fencing areas established after the flight authorization was approved. The monitoring is performed per UAS flight.	When the service detects a deviation from the requirements that can create a hazard to other aircraft operators, an alert is sent to other aircraft operators operating in the vicinity of the UAS operator, other U-space service providers and relevant authorities in such time limits that the safety objectives are met.

4.1.2.5 CIS Provider, USSP and Competent Authorities

Manned and unmanned aircraft must operate safely in both controlled and uncontrolled airspace where U-space airspace is designated. Therefore, the key task is to ensure the exchange of essential information between the U-space service providers, UAS operators, air navigation service providers and all other stakeholders within the U-space operation. The ultimate objective of U-space is to prevent collisions between manned and unmanned aircraft and mitigate the air and ground risks. This is achievable by creating a certified common information service (CIS) provider designated by the Member States. The MS designate one CIS provider per U-space airspace to ensure a single point of contact providing information of sufficient quality, integrity, and accuracy from trusted sources. The CIS as a heart of the U-space system works on the basis of open communication protocols allowing USSPs and ANSPs to exchange information through the appropriate interface. The Opinion further specifies that CIS provider and USSP cannot be a single institution so that there is no conflict of interest when the common information is made available to the different USSPs. This provision is derived more from a competition and market perspective [50].

Both CIS providers and USSPs have to undergo a certification process independently of the fact that the CIS provider is designated by the Member State as it provides the CIS on an exclusive basis whereas a USSP is only required to be certified. USSPs are not designated by the MS as there may be more than one USSP providing services in the same U-space airspace implementation. The provision of both services shall be subject to certification by the relevant competent authority established by the MS. In case U-spaces service is to be provided by the USSP across the EU, the certifying authority is EASA. The certificate confirms that a CIS or U-space service provider meets all established requirements for providing specific services to the level of performance defined for the particular U-space airspace implementation. The conditions and requirements CIS providers or a USSPs have to meet will be based on criteria similar to those used for ATM/ANS providers set in the Commission Implementing Regulation (EU) 2017/373 [50].

The Regulation drawn up on the basis of this Opinion and other European legislative processes for issuing new regulations will also address the validity of the CIS and USSP certificates on the basis of established requirements, as well as the competent authorities responsible for certification, which will be elaborated in more detail in the new regulation. It should also be mentioned that the development of the legislation is still ongoing together with a process of comments from stakeholders and at the time of elaborating this thesis, the issuance of a new regulation has been postponed due to the ongoing Covid-19 pandemic. This EASA opinion focuses rather on the UAS in the ‘open’ and ‘specific’ category, stating that the regulation issued under it will allow the harmonization of the operation of UAS in the ‘open’ and ‘specific’ category and will serve as one of the pillars for the further development of the regulation concerning UAS operation in the ‘certified’ category which this EASA Opinion mentions only marginally.

4.2 Urban Air Mobility Traffic Management

The Urban Air Mobility industry has the potential to deliver economic opportunities and urban mobility solutions that benefit communities. Realizing the benefits of implementing the UAM concept, however, requires workable solutions that ensure safe airspace coexistence, as well as community acceptance. Finding such solutions will require collaboration and planning in order to grasp the scope of future challenges. This subchapter presents a proposal based on Embraer's view of the UAM concept and its integration into ATM services. It should not be seen as a definite future state, but rather as one of many ideas that may inspire the extension of the U-space system in the future with some features that allow the U-space system to better integrate the 'certified' category of unmanned aircraft.

As stated in the *White Plan*, communities will want assurances that noise from urban flights remains in an acceptable level. In this context, it is suggested to adopt the ICAO balanced approach to aircraft noise management. Regulator and air navigation service providers will require safety, orderliness, and efficiency of UAM flights, while minimizing impact on airline and current air traffic management. Operator of small drones will want access to low-altitude airspace, while certified drones will need equitable access to urban corridors. General aviation pilots of fixed-wing aircraft and helicopters will continuously require flying above urban areas, while maintaining freedom of movement they are currently provided. In short, it is necessary that the urban airspace accommodates the needs of all stakeholders involved and therefore, it is an opportunity for community leaders, educators, city planners, transport designers, acoustical engineers and many more to participate in the implementation of the UAM concept in metropolitan areas [18].

As the concept of Urban Air Mobility becomes more universally available, current ATM system will be challenged as the pressure on urban airspace capacity will increase. Nowadays, air navigation service providers provide traffic management services for all stages of flight from gate to gate. This includes navigation services in en-route environment in high-altitude airspace, in terminal areas and in control zones of airports. ATM services are focused on managing flights between cities and their individual airports, not so much on managing flights within cities themselves with a relatively endless combination of flight origins and destinations in densely populated areas with heavier traffic and numerous obstacles. Communication is primarily conducted via radio, and surveillance technologies track aircraft, while keeping them spaced at specified distances miles apart. Current CNS technologies, airspace structures and low-altitude urban areas procedures are designed for helicopters and general aviation fixed-wing aircraft that use self-separation by see-and-avoid procedures. On the other hand, the needs of UAM flights are unique and completely different. As they will take off and land from numerous skyports across a city in a congested airspace, they will require smaller separation standards. Passengers and cargo transported by ‘certified’-category drones will be flown in closer proximity to buildings and other aircraft, over densely populated areas for most of the duration of flight, while sharing airspace with traditional helicopters and fixed-wing aircraft as well [18].

The challenge of the Urban Air Mobility concept is to define the dimensions and boundaries of the airspace designated for UAM transport and its integration into today’s rules for the ATM airspace. Define whether and where the UAM airspace will be controlled by ATC and where collision avoidance will be the responsibility of eVTOL operators or pilots. It will also be necessary to determine whether flights of smaller drones operated in the ‘open’ and ‘specific’ category will be allowed within the UAM airspace and to what altitude will the UAM airspace extend. The question also remains whether legacy aircraft will be allowed to fly in the UAM airspace and if so, how the applicability of the same rules for both UAS and general aviation aircraft will be guaranteed by air navigation service providers and aviation authorities.

The technology implemented into the ATM for UAM is also a challenging aspect. It can be assumed that if this airspace is to be managed similarly to ATM today, founding technology for this system has to be different. It will be necessary to control UAS in congested airspaces in cities, in close proximity to buildings and other aircraft, requiring an increase in the work performance of controllers, which can lead to work overload over time. In order to maintain the safety and efficiency of the operation, the number of controllers will have to be increased. A more advantageous solution for the future seems to be a higher degree of digitalization, use of smart technologies, and eventually, artificial intelligence.

However, it is likely that UAM integration into airspace will not be addressed on a unified basis in all countries or settlement structures concerned. Each area is likely to define an integration system with respect to local conditions – both in terms of the dimensional characteristics of UAM airspace and in terms of the provided services. It will be more important for UAS manufacturers to design aircraft to be interoperable in different UAM airspaces. For that purpose, some minimum equipment requirements must be established. The following Figure 8 shows the UAM airspace integration proposal from Volocopter. Blue and gray represent the airspace defined by the rules in force today. Yellow and orange represent the airspace designated for UAM. Yellow shows uncontrolled space in cities, orange shows controlled area around airports, where interactions with standard air traffic control services take place.

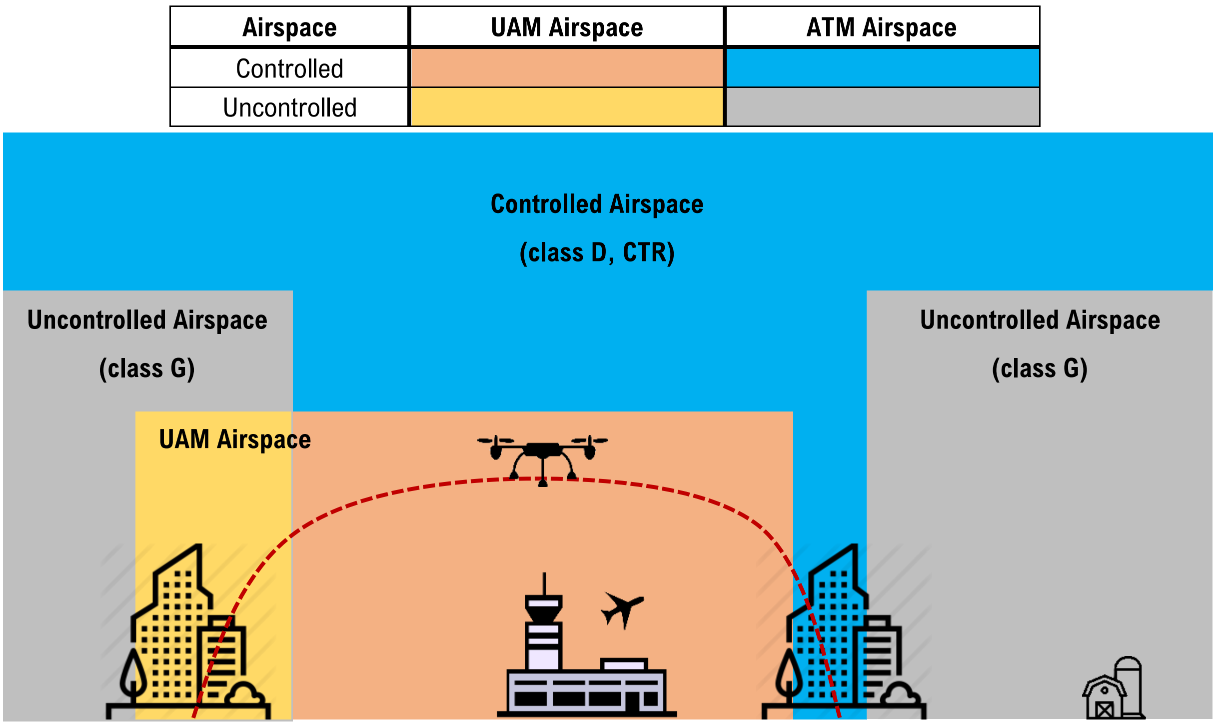

Figure 8 – Concept of integration of UAM airspace into ATM airspace [51]

UTM vs. UATM

Unmanned Aircraft System Traffic Management (UTM) is a traffic management system designed for small drones in the 'open' or 'specific' category of operation ("small drones"), for operators and involved stakeholders to interact, share information and maintain safe separation. It is similar to the European U-space system. The system is currently still under development as its framework is being refined to meet the needs of each country and region. While UTM (U-space in Europe) holds much potential for open and specific categories of drone operations, its suitability for UAM flights is problematic due to numerous reasons. The initial launch of eVTOLs will include piloted aircraft using voice communication – a mode of communication not supported by UTM. Also, there is no established authority for controlling and maintaining situational awareness of all small drones operating in a given area, which makes this framework unsuitable for executing an integrated flow management plan. When unexpected changes or emergencies arise, the UTM system is not able to provide a responsive service with a human operator capable of making timely and informed decisions. UTM is explicitly designed to support small UAS operations, not for managing traffic in a large urban airspace where some pilots rely on radio communications, while aircraft carrying people in between skyports [18].

The aforesaid issues made the reason for Embraer to propose in its *White Plan* a completely new concept of air traffic management system suitable for the UAM concept. The system is called Urban Air Traffic Management (UATM) and it will use strategically designed airspace structures and procedures to ensure urban flights remain safe and efficient, while minimizing the impact on traditional ATM. The structures and procedures forming the system will be initially enabled by technologies such as CNS, autonomy, artificial intelligence, information exchange networks and more. Further evolvement of technology will enable broadening of the system's capabilities whose role will be to ensure that UATM system remains agile, responsive, and harmonized. Each UATM implementation will need to be adjusted to the needs of the particular urban area it serves regarding the community's noise and privacy concerns, GA community inputs, skyport operators' and fleet operators' decision-making policies, etc. Emergency procedures will need to be designed in close collaboration with skyport operator in order to ensure an adequate number of emergency take-off and landing (TOL) pads are available along UATM routes. Skyport operator will also need to comply with predetermined minimum operational performance standards, and so will all UATM airspace participants. From the presented proposal of the future system for managing urban air traffic, it is possible to draw inspiration for the European implementation of a similar system created by the extension of the currently developed U-space system designed primarily for the 'open' and 'specific' category of UAS in such a way that it can serve UAS operations in the 'certified' category in the future. UATM can merge with either the U-space system or the ATM system by extending them by certain services suitable for 'certified' operation. The division could be based on whether the flight will be controlled or uncontrolled and in what airspace it will take place. The aim of this thesis is not to decide on the assignment of the UATM services to one or the other system. In the following text, the UATM will therefore be described separately, or as a partial extension of rather the U-space system, underlining that it does not have to be a future real state.

4.2.1 General description

Today's ground transportation system is made up of streets, traffic signs, traffic lights, pedestrians and cycling crossings, and other transport elements of public space. Different speed limits are required to be observed and adhered to, various signals and signs or components of smart line traffic management placed along roads alert drivers to upcoming exits and turns, and in this way, they manage traffic flows in cities. Ground infrastructure provides its users with boundaries for movement, while traffic rules create a shared understanding of how road users are expected to behave. The system conceived in such a way allows to keep everybody safely separated while moving, and more importantly, it mitigates the risk of accidents not only for moving vehicles but also for pedestrians and bicyclists who share the public space.

The concept of the UATM System represents a modern urban transit system of the future. Similar to ground infrastructure for vehicles and inspired by traditional ATM system, the UATM system will be structured with routes, corridors and boundaries defining areas where UAM aircraft may and may not fly. The structures of the system will provide predictability to traffic flows, while procedures will ensure that all stakeholders have a consistent understanding of operating rules, which combined will keep air traffic flowing and mitigate safety risks [18].

The UATM airspace may be positioned between the layers of UTM-controlled airspace intended for sUAS operations and traditional ATM-controlled airspace intended for commercial traffic. Such a layered approach to airspace enables an ANSP to increase urban airspace capacity and provide an equitable airspace access for both new and older types of aircraft within both UAM and GA (helicopters and fixed-wing aircraft) aviation. Moreover, UATM is intentioned to provide a structured traffic management system with a single airspace authority and it is designed explicitly for organizing traffic flows, mitigating risks both in the air and on the ground and supporting safety-critical situations when needed. Spatial representation of the distribution of individual functional airspace blocks of airspace within the urban environment as indicated in the *White Plan* is shown in Figure 9 below. The proposed distribution of FABs is relatively similar to the Volocopter's in Figure 8.

Figure 9 – Functional blocks within urban airspace [18]

The airspace, especially around large metropolitan areas where there are congested airports, is structured very comprehensively. There are different classes of airspace, which have defined different minimum requirements for aircraft equipment or spacing. Due to the given complexity of the airspace, such a smooth division into layers will be considerably limited and the resulting structure of the UATM airspace in the context of U-space system will look rather as presented in Figure 8.

4.2.2 Design principles

U-space airspace design principles are set out in Article 2 of the future Commission Implementing Regulation (EU) based on the EASA Opinion 01/2020. In order to be able to extend the U-space system to include the 'certified' category of UAS in UATM airspace, these principles need to be slightly expanded and specified for the system to remain acceptable, safe, and equitable for all the stakeholders involved. The core principles for the design and building of a UATM system defined in the *White Plan* can serve this purpose [18]:

1. **Providing shared situation awareness for all stakeholders**

   The system must provide all stakeholders involved with access to the same accurate and timely information in order to gain ability for making informed decisions to maintain operational safety.

2. **Maintaining equitable airspace access for all stakeholders**

   Appropriately equipped and registered aircraft must be allowed to gain equitable access to the UATM airspace.

3. **Minimizing risk to operational safety**

   Risks to operational safety must be minimized or mitigated by ensuring that UATM safety performance meets or exceeds that of the current urban airspace operations.

4. **Optimizing airspace use**

   Capacity of the urban airspace system must be designed by using strategically positioned airspace structures and applying traffic management procedures.

5. **Ensuring airspace structures are flexible and adaptable**

   Airspace structures such as boundaries, routes and corridors that can be activated, deactivated, or moved in response to traffic demands, weather conditions and other changes in UAM operation conditions must be developed and established.

4.2.3 Urban Airspace Service Provider

An urban airspace service provider (UASP) is a single entity that is to be responsible for managing low-altitude urban air traffic. The UASP shall deliver a series of services for urban air traffic in close collaboration with ATM, UAS service suppliers and UATM stakeholders. Based on the concept of UATM as a kind of a "superstructure" of the U-space system, this role can be taken over by the U-space Service Provider (USSP) in U-space airspace. *(For resolution purposes hereinafter still referred to as a UASP, although it can be presumed that in the future both providers will be a single entity., n.b.)* It is assumed, however, that within the UATM airspace, partially ATC-like services will be provided to individual UA operators. EASA does not anticipate this in its Opinion and assumes that this kind of services will have to evolve gradually.

As a single authority for managing urban airspace, the UASP may also have authority over opening and closing routes, granting flight authorizations, and executing a single, integrated flow management plan. The UASP may be responsible for collecting, analyzing, and exchanging airspace and flight information to support operations with a high level of safety. In case of an emergency or off-nominal situation in flight, the UASP may have human operators to communicate with pilots and fleet operators, while guiding aircraft to safety. Another UASP's key role might be enhancing and maintaining the safety of the UAM industry. Its safety management system will capture operational safety reports and address improvement efforts accordingly. Beyond physical safety of the UAM industry, cybersecurity will have to be considered as well, and achieved necessarily by developing and operating cyber-resilient systems [18].

There may arise different approaches to how cities and countries will establish an urban airspace service provider which will mostly depend on the local ANSP, regulations, policies, strategies, and availability of resources. A number of possible scenarios can be followed in implementing rules for urban air traffic. Some countries may decide just to extend the current role of the local ANSP to managing low-altitude urban airspace. Other countries or states may decide to assign UASP responsibilities for each city or a cluster of cities to a third party. This will result in inevitable differences between countries as allocation of authority to a UASP will vary. It is, nevertheless, crucial to establish a central authority for managing UAM airspace of each urban area in order to ensure that air traffic flows safely and efficiently using a single flow management plan [18].

4.2.4 UATM-related services

In order to achieve the abovementioned objectives, UATM system, similar to a traditional ATM system, will be comprised of several services essential for building such a system. A proposal of the services provided to the 'open' and 'specific' categories of drones within the U-space system with the UATM services presented in the *White Plan* together can serve as a good basis for the implementation. There are defined six services in the UATM concept. Table 7 below describes UATM system-supporting services and their role in a process together with an indication of the corresponding service proposed under U-space. A more detailed description of each service follows the Table 7. Due to the fact that each airspace is under authority of distinct laws, regulations and different ANSPs, details for roles and related responsibilities may be decided accordingly. The most probable scenario within the European Union is that the individual services and their role will exist and function as defined by U-space, with the proviso that for their usability for the operation of the 'certified' category of UAS they can be adequately modified.

Table 7 – Comparison of UATM and U-space Services

UATM Service	Description	U-space corresponding service
Airspace and Procedure Design Creating urban airspace routes, corridors, and procedures	Pre-planning routes, corridors, airspace boundaries and procedures for safety and environmental concerns while maximizing use of airspace.	**U-space designation** *(done by the Member States) – not provided by a USSP*
Information Exchange Exchanging airspace and flight information with all stakeholders	Sharing information with all stakeholders in UATM and adjacent airspace management systems such as ATM and UTM in order to provide critical information enabling operational services.	**Common Information Service** *(designated by the Member States) – not provided by a USSP*
Flight Authorization Authorizing registered aircraft and pilots for flight in UATM airspace	Receiving flight requests, identifying optimal routes, and assigning 4D flight requirements before authorizing a flight for UATM operations.	**Flight Authorization** *(mandatory)*
Flow Management Spacing aircraft to maintain the integrity of the UATM operation	Managing the volume of traffic and assigning metering times to ensure safe spacing of aircraft.	***unassigned***
Dynamic Airspace Management Managing routes, corridors, and airspace boundaries dynamically	Shifting pre-planned routes, corridors and geofenced areas when flight restrictions are activated. Moving, opening, and closing routes in response to flow management needs, ATM needs and changing weather conditions.	**Geo-awareness** *(mandatory)*
Conformance Monitoring Ensuring flights conform to flight and assisting pilots during off-nominal situations	Monitoring all traffic to maintain safety and provide guidance for any deviations. Giving aircraft in emergency situations immediate assistance and activating airspace and traffic flow adjustments to keep flights safe.	**Conformance Monitoring** *(supporting)*

Regarding **Airspace and Procedure Design**, airspace structures, such as routes, corridors and boundaries, and procedures are crucial in enabling existing traffic consisting of fixed-wing aircraft and small UAS (open and specific category) to coexist safely with e VTOLs while maximizing the capacity of urban airspace. Given the complex mix of aircraft equipage, airspace structures will be critical for organizing traffic and managing traffic flows. Rules may differ in different airspace structures as access to some corridors may be restricted and lower altitudes may be reserved for open- and specific-category drones. High-capacity corridors within UATM airspace may require certain types of equipment and certification of both aircraft and crew, similar to performance-based navigation routes within the ATM airspace. Defined routes and corridors will be an important tool for avoiding conflicts, and procedures will ensure that all stakeholders involved interact safely and share consistent situational awareness [18]. Within the UATM system based on U-space, it is similar to the designation of U-space airspace performed by a MS through a competent institution, in this case ANSP or CAA, which would designate a U-space airspace.

Information Exchange will be crucial in making informed decisions based on consistent sets of data. Information must be timely, consistent, accurate, and accessible to all stakeholders in order to provide conditions for their quick, efficient, and safe collaboration. Similar to the approach taken by collaborative decision making in commercial aviation. Since the UAM airspace will be a dynamic place where a status of skyports, corridors and routes changes quickly, information exchange must be rapid and effective. Since data will be exchanged across numerous systems, its format will need to be standardized and it will have to be protected by a cyber-resilient network developed within a cybersecurity strategy [18]. Within U-space-based UATM, the so-called Common Information Service (CIS) established by a MS through a competent authority can serve as Information Exchange. The system can be partially imagined as similar to Flight Information Service provided within a traditional ATM.

Flight Authorization will provide fleet operators and pilots with a clearance to fly in UAM airspace. It will include an assigned route and, if necessary and possible, a 4-D metering requirement. The flight authorization is a critical service that may help in strategic planning, conflict avoidance and flow management. It will enable fleet operators and pilots to be confident that the flight is strategically deconflicted and that the requested routes, corridors, and airspace will be available at departure.

In order to obtain a flight authorization, a fleet operator would need to submit a flight request to the UASP using the information exchange service, containing basic details such as departure and optionally, routes and corridors. Then the UASP automation can check for the certification level of the aircraft and calculate the optimal route. Once the authorization is approved, it can be sent to the fleet operator and the pilot. The flight authorization may include departure time, 4-D requirements for metering points in routes and a slot time for arrival. Afterwards, the pilot may accept or reject the authorization [18]. The role of the Flight Authorization is the same in both systems. For its operability in the UATM, it must be adapted to meet the conditions imposed in the future to enable the operation of the 'certified' category of UAS.

The goal of a **Flow Management** is to optimize airspace capacity, minimize congestion while traffic demand fluctuates over the course of the day. This can be accomplished by means of technologies such as predictive analysis and time-based metering models. Time-based metering can be used to regulate traffic flows and strategically deconflict aircraft along predetermined routes from departure to arrival. In case that a need for shift in corridors and airspace boundaries arises with demand or other conditions, the flow management would need to respond accordingly in order to supply a steady stream of aircraft to optimize airspace use. Flow managers can determine the optimal departure release times, landing times and slots in the routes and corridors by using 4-D trajectory models. Once airborne, automation can monitor the progress to ensure metering times are met and safe spacing is maintained based [18]. In the currently proposed U-space system ('open' and 'specific' category of drones) the role of Flow Management is performed only by the established rule that if two aircraft are assigned the same level of priority, the aircraft that arrived first has a "right of way". This may or may not be sufficient for a 'certified' category of traffic within a UAM, depending on the level of traffic density and rules in the airspace. However, it is not the task of this thesis to evaluate such approach.

Dynamic Airspace Management represents a core service to enable continuous and flexible UATM operations. The UASP can have a predefined set of airspace structures that are strategically positioned to support the dynamic needs of UAM stakeholders. During the course of daily operations, the UASP will open, close, and move routes, corridors, and airspace in response to traffic demands, weather conditions, emergencies etc. When, for example, the ANSP restricts access to a section of airspace or creates a temporary flight restriction, the UASP will factor in this change when assigning routes with flight authorizations. In emergency situations, dynamic airspace management will be critical for shifting airspace structures as necessary and notifying airspace operators of an emergency situation by data updates in the information exchange in case of noncritical adjustments, or by voice communications when the information needs to be extended urgently [18]. This key role may be performed in the U-space system by the extended geo-awareness service adapted for 'certified' UAS operation.

The last service described is **Conformance Monitoring** which is a part of the system ensuring by means of automation that each UATM flight is conformed to the authorized route and 4-D metering requirements throughout the duration of the flight. This may be important especially in dense corridors, where a potential failure may have a strong negative impact on safety and efficiency. If the automation predicts that a metering requirement will not be met, a fleet operator or a pilot can be prompted to adjust the speed, route, or altitude in order to remain conformed to its 4-D requirements [18]. The role of the Conformance Monitoring is the same in both systems. For its operability in the U-space, it must be adapted to meet the conditions imposed in the future legislative development to enable the operation of the 'certified' category of UAS.

Other U-space services that enter the process but are not mentioned in the UATM concept are the network identification service, which is the input to the Flight Authorization service and other services through the CIS, and the supporting weather information service entering the CIS and the extended geo-awareness service. All aforementioned UATM services are interdependent and can only operate safely and effectively as a single unit. The flow of data and information between these services takes place at different levels and these interdependencies inspired by the Embraer's *White Plan* and modified into a form based on the U-space system are shown in Figure 10. The diagram shown can serve as a proposal and an inspiration for further legislative developments.

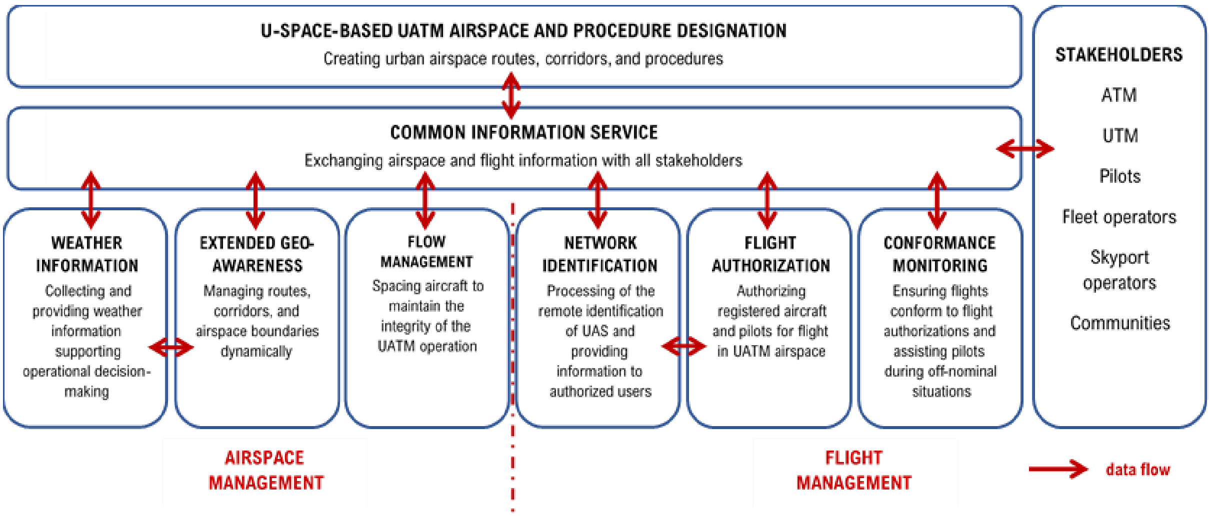

Figure 10 – U-space-based Urban Air Traffic Management System diagram

A traditional ATM system is comprised of Air Traffic Services (provided by an ANSP), Airspace Management and Air Traffic Flow and Capacity Management. The UATM (extended U-space) system, consisting of the services depicted in the diagram above, should be considered in a similar vein. Within the system, it would be the responsibility of a UASP (USSP in the U-space system) to provide the six services listed above and divided into airspace management services and flight management services. At this point, it must be emphasized repeatedly that this is only an inspiration for the extension of the U-space system for the 'certified' UA category, not the final desired state. The division of services, their individual roles and mutual data flows in the overall system may vary depending on the needs of states and their respective regulators and will continue to be the subject of wider professional debate.

4.3 Air Navigation Services of the Czech Republic and UAM

Current operational possibilities of UAS exceeding 150 kg (according to the latest European legislation in force: in the 'certified' category) were already described in more detail from the perspective of Czech legislation (Supplement X to the national Regulation L2) and the European legislation in the chapter 1.3. The national Supplement X does not allow the operation of unmanned systems with a fully autonomous control system. Manned VTOLs are currently subject to rules adopted for general aviation.

The operation of UAS in the airspace of the Czech Republic is handled in accordance with Regulation L2 and its Supplement X until 31 December 2020. In operational terms, UAS operation is handled independently of MTOM. In the context of the integration of unmanned systems into airspace from an air traffic control perspective, interactions with UAS are expected to happen close to controlled aerodromes at the distance of less than 5.5 km or above 100 m AGL within the CTR zone of the aerodrome and anywhere else above 300 m AGL. At present, UAS of various types flying under IFR also sometimes use the airspace of the Czech Republic for various purposes. In their case, communication and the provision of air and navigation services shall take place as usual with any other aircraft within the ATM system, considering the different performance characteristics of such an unmanned aerial system and, consequently, issuing appropriate and enforceable instructions by an air traffic controller.

For the future development of the Urban Air Mobility concept in the Czech Republic, the implementation of the U-space concept is necessary. According to the ANSP of the Czech Republic itself, the implementation of the U-space in the Czech Republic is at a very early stage. At present, Air Navigation Services of the Czech Republic participate in the EASA's concept in the form of a comment procedure. At the time of writing this section, the EASA Opinion 01/2020 was the subject of a comment procedure on the basis of which the European Commission would prepare the European U-space Regulation. The European Commission intends to process the EASA Opinion 01/2020 into a Regulation by the end of 2020, but a later date can be expected due to the wishes of major European aviation entities for a more thorough discussion and elaboration of this issue. Air Navigation Services of the Czech Republic also deal with this issue in cooperation with the Czech Technical University in Prague.

Air Navigation Services of the Czech Republic is considering the integration of all types of UAS currently under discussion into the air traffic management system in the future, including the integration of the UAM concept and autonomous UAS. It stresses, however, that in the case of autonomous operations, it is necessary to resolve the legal aspect of the matter where the commander is not responsible for the operation of such aircraft. The legal aspect of the matter seems to be the most problematic facet of the deployment of autonomous UASs. It is already mentioned and described more in detail in the subchapter 3.2. For clarification, it is not addressed at all in the framework of the UATM system, whose concept is represented by Embraer's *White Plan* described in the previous subchapter of the thesis, nor is it widely mentioned in EASA Opinion 01/2020 on the implementation of the U-space system. It is assumed that in the first years of the introduction of the UAM concept (whether in the Czech Republic or in the world) it will be a manned piloted eVTOL operation with passengers or cargo on board. In the beginning, therefore, UAM will be operated as a classic aviation, and the condition for integration into U-space airspace will be the sharing of identification and location towards USSP applications.

The new arrangement of airspace in the form presented within the UATM concept, i.e. the form of a new 'certified'-UAS airspace layer between the VLL airspace for the 'open' and 'specific' category UAS and the layer for conventional aviation, will be a matter for further discussion by stakeholders. Flight Authorization will be one of the basic U-space services, which is to be created by a forthcoming Regulation of the European Commission. The whole concept should be further developed with additional levels of services, where services such as Flow Management are also considered since they are essential for denser urban traffic.

In addition to the development of European rules, Air Navigation Services of the Czech Republic are actively involved in ICAO activities, within which rules for the operation of remotely piloted aircraft systems (RPAS) operated internationally under IFR rules are currently being under development.

Regarding the differences in approaches to the integration of UAS into the ATM system in different countries, Air Navigation Services of the Czech Republic consider the exchange of information to be good, given the ongoing cooperation in the various working groups. The concept of the basic legal framework for UAS regulation is more or less similar in all parts of the world, where it is being under development. The differences that occur are due to the UAS regulatory framework being implemented into the different legal systems of individual countries. Further development, not only in the Czech Republic but in the other countries as well, will depend on smooth cooperation at the local level between the Ministries of Transport, Civil Aviation Authorities and Air Navigation Service Providers, and at the international level between EASA, ICAO, MSs, etc. so that the Czech Republic, other countries and the European Union as a whole with its ambitions do not lag behind in their efforts in global UAS integration, including future UAM operations.

5 Autonomous Flying

Air transport is by far the safest transport mode in terms of statistics. This is repeatedly confirmed by statistics from reputable institutions such as Eurostat, EASA or Bureau of Transportation Statistics (BTS) at the U.S. Department of Transportation. Much more casualties are recorded by other modes of transport, especially road transport and pedestrians. According to BTS, up to 39,000 fatalities occurred related to transportation in the United States alone in 2017, of which more than 37,000 lost their lives in road accidents. In air transport, 'only' 346 people lost their lives, representing less than 1 % of the total number of fatalities in transportation [52].

Today's high level of aviation safety results from various factors. Since its inception, aviation has undergone a long-term development that can be divided into several phases. At the beginning of the 20th century, when the aviation was still inaccessible and uninteresting in terms of transport, the aircraft were dominated by biplanes with fuselage gondolas, frame construction and open cockpits. With World War I and increased demand for military machines, aircraft began to become more specialized and engines and fuselage structures had also evolved. An even greater shift in development came with World War II, which demanded longer-distance flights across the oceans, a closed, sound-insulated cockpit, and a retractable landing gear to reduce aerodynamic drag, increasing operational economy and overall machine reliability. The period after the war brought a revolutionary innovation in the form of a jet engine. The jet engine was much more reliable, the speed of flight increased, the design characteristics of aircraft improved, travel times were reduced, making air transport interesting for increasingly wider masses of people. The new fly-by-wire control system introduced in the 80s which replaced the conventional manual flight controls with wire-transmitted electronic signals to move control surfaces of the aircraft. After an unsuccessful, too costly, and unsustainable developmental branch in aviation, supersonic flying, and with the emergence of new threats in the form of terrorism, increasing emphasis began to be placed on air transport security, which was reflected mainly in the introduction of new security policies, especially in ground handling of aircraft, but also in some design elements, e.g. reinforced cockpit doors, etc. With the advent of the present time, when the aviation industry has been quite successful in reducing security threats, ecology and its associated elements have become a new trend. More effective, larger, and quieter engines have been put into operation, and experiments are also taking place in the field of alternative types of drive power in the form of electric or hydrogen propulsion. The lightweight composite materials, from which today's new machines are constructed, have reduced the overall weight of aircraft, enabling their cleaner aerodynamic profile and reduced fuel consumption.

To summarize, the aviation has gone through a development that involved a lot of experimentation and a significant loss of lives in numerous air accidents. The positive knowledge, however, is that each tragic event was a lesson for aviation and led to total or at least significant elimination of other similar errors. New safety features such as Safety Management System, Just Culture, mathematical models of safety, predictive analyzes, etc. have been introduced. Nowadays, there are thoroughly designed procedures for aircraft operations, certification specifications for introduction of new aircraft, checklists for crew responses to abnormal situations, as well as periodic maintenance inspections of machines carried out at prescribed regular intervals. These safety measures are based on enormous legislation imposing safety requirements on all aviation stakeholders. National and multinational aviation authorities, which closely monitor compliance with the rules set by the legislation, also play an important role in the process. The fact that aviation is one of the most strictly regulated sectors, which is reflected in the positive accident trends as well, is one of the important reasons for the general confidence and attractiveness of this mode of transport among customers.

5.1 Introduction of artificial intelligence

Artificial intelligence is defined from a wider perspective as a technology that is capable of emulating the performance of a human. The basic division of artificial intelligence types is determined as follows: model-driven AI and data-driven AI, or their combination also known as hybrid AI. The current breakthrough of AI is linked with so-called machine learning (ML), which is the use of data algorithms to improve their performance. This will be a strategic technology for years to come as it is capable of improving not only aviation and transport in general, but also healthcare, energy, resources, finance, or justice. The same as with UAS, the varieties of use of AI are only limited by the imagination of individuals [53].

The introduction of artificial intelligence into aviation, its management and other activities is probably becoming a new phase of evolution of aviation and it is highly likely to be significant in the introduction of new technologies in the 21st century. As EASA states in its roadmap on artificial intelligence being adopted widely, the concept of AI has long been in existence but its development accelerated in the last decade due to three concurrent factors, which are capacity to collect and store massive amounts of data, increase in computing power and development of increasingly powerful algorithms and architectures. The document further predicts that AI implementation into the aviation sector will not only affect products and services provided by the industry, it will also trigger the rise of new business models [53].

The drone market has paved the way for the emergence of new business models such as the creation of air taxi systems as a response to the demand for urban air mobility. Autonomous vehicles will inevitably have to rely on systems to enable complex decisions, e. g. to ensure the safe flight and landing or to manage the separation between air vehicles with reduced distances compared to current ATM practices. To enable full autonomy, powerful algorithms will be necessary to cope with the huge amount of data generated by the embedded sensors and by the machine-to-machine communications. The implementation of AI solutions to cope with larger number of drones will not be possible using traditional approaches.

5.2 Legal aspect of autonomous operation

The subchapter concerning legal aspect of autonomous operation is presented in this section of the thesis merely for the completeness of the topic. The issue is already described in more detail in the chapter 3.2.

5.3 Artificial Intelligence Trustworthiness

Artificial Intelligence, most probably more than any other technological fundamental evolutions so far, raises major ethical questions. A European ethical approach to AI is central to strengthen trust of citizens in the digital development. The EASA Roadmap on AI states that AI can be considered trustworthy only when it is *"developed and used in a way that respects widely shared ethical values"*. It emphasizes the need for ethical guidelines that build on the existing regulatory framework.

The power of a machine learning process lies in the capability of a system to learn from a set of data rather than requiring development and programming of each necessary decision path in a software. The deployment of such systems in the operation of unmanned vehicles will require resolving the challenges essential to the trustworthiness of the AI-based system. Despite the fact that many of the challenges are already at a certain stage of the solution, it can be stated that many more steps requiring a lot of work will need to be taken to allow fully autonomous flight of an UA. The EASA Roadmap on AI describes some of the currently identified challenges, among which there is a need for a shift in paradigm to develop specific assurance methodologies to deal with learning processes since traditional development assurance frameworks are not adapted to ML. ML application behavior is unpredictable and unexplainable as ML applications are probabilistic by nature. Even if a ML model is mathematically deterministic for a new input, the output will depend on the correlation between that input with the data set that was used for the training process. Due to the statistical nature of ML applications, they are subject to variability on their output for small variations on their input. There is therefore a need to investigate new methods for verifying the robustness of the ML applications, as well as to evaluate the completeness of the verification. Also, the operational performance of the ML applications is hard to assess and evaluate since standardized methods are not existent yet. Reference metrics on accuracy or error rate of a ML application must be investigated and established. While gaining experience, it was figured out that ML solutions are subject to bias and variance, which can compromise the integrity of their outputs. The document claims this to be the most challenging aspect of collection, preparation and usage of data – the capability to identify, detect and finally mitigate adequately any bias or variance that could have been introduced at any time during the data management and of the training processes. The last but not least challenge with implementing artificial intelligence into aviation are adaptive learning processes. Real-time learning in operations is a parameter that will introduce a great deal of complexity in the capability to provide assurance on the ever-changing software. This is incompatible with current certification processes and would require large changes in the current regulations and guidance. This is at this stage considered a much more complex issue that may require to be bounded [53]. There exist many other issues that need to be addressed and that are far beyond the scope of this thesis going too deep into computer science and neural networks.

From the point of view of the operator and the user of UAS, it should be added that if artificial intelligence is ever to be introduced and fully implemented into real air traffic taking into account all facets of aviation industry, including aircraft design and operation, production and maintenance, air traffic management, safety risk management, cybersecurity, and environmental issues, and also if it is to be applicable to UASs in the 'certified' category and in general aviation, it will be necessary to ensure that the level of operational safety and the level of confidence of both the lay and professional public towards aviation is maintained. This will include, in addition to a number of other problems, addressing these aforementioned challenges.

5.4 Sense-and-Avoid System

One of the challenges mentioned in the previous subchapter is a safety risk management and related to this is the issue of collision avoidance in traffic. Drones are currently used for various purposes, including aerial works in civilian use or military operations. As the airspace becomes more congested with these UASs, the risk of collisions between drones with each other and possible obstacles in the airspace also increases. Small drones are also often used in building interiors, where the risk of collision with an obstacle is many times higher. Undoubtedly, this challenge must also be addressed in the area of large drone operations in the 'certified' category (for both piloted and autonomous flights), where passengers and dangerous goods will be transported in the vicinity of other operations and urban areas. The risk for 'certified'-category UASs is a collision with sUAS, with another 'certified'-category UAS, but also with conventional transport in commercial and general aviation. Given their intended operation in metropolitan areas and in cities themselves, especially near buildings, electricity pylons and cables, trees and other obstacles within urban space, the need for collision avoidance is all the more acute.

The solution for the issue has to be a sort of a collision avoidance system which in the operation of UAS is called the Sense and Avoid (SAA) system and is currently under development mainly for the operation of drones in the 'open' and 'specific' categories for both VLOS and BVLOS flights. The relevant regulation will require the SAA system to be installed on each UAS in order to reduce collision risk and enhance safety of operations.

Several SAA-related sensors have to be mounted on the UAS to collect and record data along the flying path. During the operation, the sensors will detect and identify obstacles and threats by providing information of environmental mapping. The data will be gathered and processed in the collision avoidance program in the main processor and the UAS will execute the avoidance action accordingly, depending on the information about the obstacle and taking into account several factors such as presence and position of intruders as well as the speed and trajectory predictions. The system should be based on several effectuating technologies using different sensors – cameras capturing visible and infrared light, electro optical sensors, millimeter wave radar, LiDAR, traffic collision avoidance system (TCAS), ADS-B, etc. For instance, the big advantage of the ADS-B system is that it not only provides status vector about aircraft's altitude and velocity, but it is also capable of providing weather information or topographic terrain information [54]. A basic simple diagram of how the system should work provided the process of collision avoidance is automatic is shown in Figure 11.

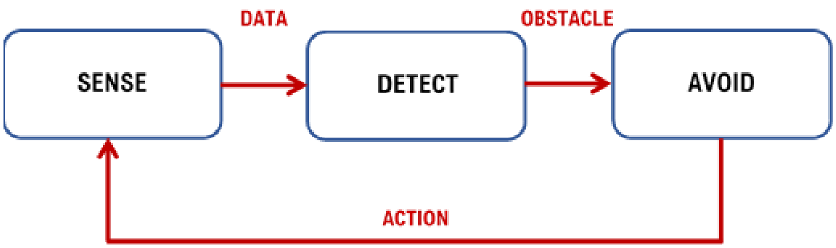

Figure 11 – Sense-and-Avoid System diagram [54]

Within the functionality of the SAA system on the sUAS in 'open' and 'specific' category, the size, weight, and power consumption of the system are addressed since they are crucial for small drones with weights in grams to units of kilograms. The aim is to install such a system on drones with lower operating speeds, which, moreover, often move in interiors, where cooperative systems are not usable due to the type of possible obstacles. For 'certified' UAS, the weight of the SAA system need not be given so much importance given the expected size of eVTOL aircraft. The system is likely to be based on a TCAS system already functioning in general and commercial aviation within the ATM system. However, it must be adaptable to different weather and light conditions in order to maintain its functionality even in metropolitan-area flights with lower separation minima while maintaining sufficient level of safety. Further development in the field of AI, neural networks or big data analysis tools will be essential for the SAA system to fully develop into usability in 'certified'-category of UAS operation.

6 Certification of Unmanned Aerial Systems

Prototypes of drones originated during the 20th century. The idea of their use and subsequent implementation of projects expanded mainly in the field of military operations and the army in the 1960s and 1970s. Further expansion was made possible, in particular, by the development of new technologies which enabled better affordability and usability. Expansion to civilian and commercial use occurs in the 21st century, more markedly after 2010 with the development of smart technologies and more capacitive and faster communication networks. The decline in the prices of UAS has made them widely available to a broader scope of users, which in turn has thickened airspace and many occurring incidents have begun to affect both civil and military aviation, seriously undermining the then sufficient level of safety in terms of protection of people and property. States, transnational entities, and other stakeholders involved in the air transport market have recognized the need to regulate this new aviation sector, which would help increase the level of safety and establish uniform rules and conditions for the civilian use of UAS. The need for regulating UAS is clear and the same as the need for regulating aviation in general. The purpose of certification is to ensure an appropriate level of safety. The clients of the national aviation authorities and EASA are all, i.e. also persons not involved in the operation of aircraft, including UAS. These persons must be provided with an appropriate level of safety, which can only be guaranteed by regulating both the aviation as such and the operation of the UAS itself.

6.1 Introductory overview

Urban air mobility UASs are very similar to a traditional airplane in terms of performance characteristics. They can be seen as airplanes with an "unconventional" mode of take-off and landing, which are indistinguishable from the conventional airplanes during the forward flight phase for almost the entire duration of the flight. Many are also capable of conventional take-off and landing (CTOL), and merely as if in addition, they can handle stall-like landings with a gradual reduction in forward speed and descent along a sort of a concave parabolic curve followed by landing on a landing surface (a vertiport or a skyport), or a perpendicular landing as a helicopter. However, due to the fact that hovering requires a lot of energy, since the lift during this phase is not created by the forward movement of the aircraft, but only by the rotors, the hovering mode is not efficient and therefore its use is expected only in the minimized time interval within the flight duration. Thus, more than drones that will occupy airspace over populated areas in hovering mode, eVTOLs are almost conventional airplanes with certain performance differences.

In the beginnings of modern civil aviation, especially at the time of the advent of jetliners as a completely new concept in air transport, the approach to certification of airworthiness was much different from how it is today. Most regulations and certification requirements were relatively "soft" in terms of safety, mainly due to the fact that they were often developed on an ad hoc basis. The aircraft were first designed and built, and only after, based on the experience from operating the machines, the rules were created or tailored as needed. Today's conditions are, however, quite challenging for the development of new concepts, such as eVTOL UA within the concept of UAM, as the aviation has gotten into a much more mature state over the years. Certification procedures require an aircraft to be constructed in such a way that it complies with the strict requirements set out in the regulations already established. The problem is both technological challenges and a massive regulatory environment developed during decades of operation, which is considerably rigid for new concepts and its change is very difficult, though possible.

One option for new types of UAS such as eVTOLs is the need to reform and completely redesign the enormous system of rules in terms of certification requirements for aircraft, in terms of integration into airspace with the detailed procedures related to controlled/uncontrolled airspace conditions, ATC procedures, requirements on CNS equipment, and also in terms of ground-based air transport infrastructure. However, this possibility seems almost impossible given the amount of energy necessary for such a revolutionary change to happen. The second and much more transitable approach is to "fit" into this enormous system of rules with its slight variations, as in the early days of civil aviation, when rules often evolved on an ad hoc basis, to develop and evolve a system of rules and legislation gradually to such an extent that eVTOL operation becomes a standard part of air transport system.

6.1.1 Overall certification framework

The certification basis for UAS is constantly evolving. EASA, as an aviation regulatory body operating in the territory of the European Union, is currently (August 2020) concentrating its activities in the field of UAS regulation mainly on drones in the 'open' and 'specific' categories. This is mainly the development of the U-space system. The issue, together with the description of the legislative framework, has been described in more detail in the previous chapters of the thesis. As far as the UASs in the 'certified' category are concerned, the certification basis and the corresponding legislative framework are still at a very early stage of the development regarding their heterogeneity across individual countries and transnational entities.

The following Table 8 provides an overview of the selected certification basis at several levels, based on which the certification of aircraft and UAS takes place for now. The reason for the experimental category of aircraft to be included in the following overview is that the current prototypes of future 'certified' drones are being treated as the experimental category of aircraft according to today's legislative conditions set out in the legislation framework of the Czech Republic. The experimental category is described in more detail in chapter 6.3.3.

Table 8 – Legislative framework for the certification of UAS and selected categories of aircraft

ICAO (global perspective)
– Annex 8 to the Convention on International Civil Aviation – Airworthiness of Aircraft
EASA (EU perspective)
experimental aircraft
– Commission Delegated Regulation (EU) 2020/570 – Part 21 - Acceptable Means of Compliance and Guidance Material for the airworthiness and environmental certification of aircraft and related products, parts, and appliances, as well as for the certification of design and production organizations – CS-23 – Acceptable Means of Compliance and Guidance Material to Certification Specifications for Normal-Category Airplanes (CS-23) – CS-27 – Certification Specifications and Acceptable Means of Compliance for Small Rotorcraft (CS-27)
unmanned aerial systems
– AMC and GM to Part-UAS – UAS operations in the 'open' and 'specific' categories – SC-VTOL-01 – Special Condition for small-category VTOL aircraft   – MOC SC-VTOL – Proposed Means of Compliance with the Special Condition VTOL
Federal Aviation Administration – USA (local perspective)

– Title 14 Code of Federal Regulations (14 CFR)
    – Part 21 – Certification Procedures for Products, Articles, and Parts
    – Part 23 – Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
    – Part 27 – Airworthiness Standards: Normal Category Rotorcraft

Civil Aviation Authority of the Czech Republic (local perspective)
– Aviation Regulation L8 – Airworthiness of Aircraft – Aviation Regulation L8/A – Airworthiness of Aircraft-Procedures

6.1.2 Aircraft certification process

The key document on which the aircraft certification process is based is ICAO Annex 8 – Airworthiness of Aircraft. From the document, each ICAO Member State derives its own legislative framework for implementing certification standards. In the European Union, the procedures for certification of aeronautical products are contained in Regulation (EC) 748/2012 Annex I – Part 21, including the procedures for the approvals of design organizations and production organizations. These approvals must be obtained prior to obtaining the product certification. Within the EU, EASA as a regulatory body lists the requirements for certification as a set of certification specifications (CS), whereas in the USA, these requirements are listed as airworthiness standards and are issued by the Federal Aviation Administration as individual 'Parts'. The type-certification process for aircraft in general (not necessarily just for UAS) consists of four steps defined by EASA (however, also applicable globally) as follows [55]:

1. Technical Familiarization and Certification Basis

- an aircraft manufacturer presents a project to EASA (or a NAA) when it is considered to have reached a sufficient degree of maturity after which EASA (or a NAA) establishes a certification team and a set of rules (Certification Basis) for the certification of the specific aircraft type;

2. **Establishment of the Certification Program**
   - EASA (or a NAA) and the manufacturer define and agree on the means of demonstrating compliance of the product type with the Certification Basis together with the identification of the level of involvement of the NAA during the certification process;
3. **Compliance demonstration**
   - the manufacturer demonstrates compliance of the aircraft and all of its elements such as performance, flying qualities, construction, etc. with the Certification Basis;
   - EASA (or a NAA) performs a detailed examination of this compliance demonstration done by analysis combined with ground and flight testing;
4. **Technical closure and issue of approval**
   - once EASA (or a NAA) is satisfied with the compliance demonstration by the manufacturer, the investigation is closed, and a Type Certificate is issued;
   - EASA states that the primary certification is delivered for European aircraft models which are also being validated consequently by foreign authorities for operation in their airspaces based on bilateral agreements.

In order for a civil aircraft (including UAS in the 'certified' category) to be able to fly, in addition to the Type Certificate, it must also obtain a Certificate of Airworthiness. The following division explains the difference between the two certification approvals [56]:

- **Type Certificate –** a document is issued by a state to define the design of an aircraft, engine, or propeller type and to certify that this design meets the appropriate airworthiness requirements of the state;
- **Certificate of Airworthiness –** a document is issued for a specific aircraft to confirm the status of the aircraft, engine, propeller, or part conforms to its approved design and is in a condition for safe operation.

The following subchapters deal with the legislative frameworks for certification of UAS and aircraft in general from an international and a national perspective. It is necessary to look at them not in terms of the superiority and inferiority of individual legislations, but rather as legislative frameworks that complement each other and whose form is yet far from final due to the still ongoing development of this new area of aviation.

6.2 International legislation

6.2.1 ICAO – Airworthiness of Aircraft

In order to assess the certification requirements for aircraft and UAS, it is necessary to return back to the basic key document – ICAO Annex 8. The requirements for meeting the conditions for enabling the certification are divided according to the MTOM of the aircraft. Since this thesis deals with the certification of UAS over 150 kg, while most UAM aircraft concepts described in the previous chapters fall into the category with MTOM up to 5700 kg, the certification requirements applicable to these machines are described in Part V of Annex 8 – Small Airplanes. For UAS with an MTOM higher than 5700 kg, the applicable requirements are described in Part IIIB. The document structures the certification requirements into individual chapters, as is customary by default for other documents of this type (for example, those issued by EASA). General applicability, flight and performance requirements, structure in terms of weight distribution, speed limits, etc., requirements for design and construction, powerplant, system and equipment, operating limitations, cabin safety and operating environment are described in detail.

However, not all requirements are applicable to the certification of the 'certified' UASs, as the document does not mention at all VTOL capability, which is an inseparable feature of UASs, and describes tailor-made requirements for aircraft with a "classic" take-off and landing mode. For example, the requirements set out the performance characteristics that an aircraft must meet during the individual phases of flight – take-off, en route and landing – in the event of engine failure, without taking into account the ability of an UA to hover. One possibility is then to combine the requirements imposed in Part V for small airplanes with the requirements for the airworthiness of helicopters, which are described in the similar structure of the division of requirements in Part IVB of the given document. In particular, these would be requirements for performance, flying qualities, and stability and control of the aircraft, which are somewhat similar to helicopters at UASs. The combinability of certification requirements applied to different types of aircraft for application to the UAS will require a wide discussion of experts in the field of aviation safety and aviation law and is beyond the capabilities of this thesis. An amendment to ICAO Annex 8 is also offered as an option to introduce a completely new category of aircraft, such as UAS with an MTOM exceeding 150 kg and not exceeding 5700 kg (or 8618 kg as explained in the proposed CS-UAS document described later in the text) with the possibility of further subdivision of weight categories according to different properties, e.g. VTOL capability, etc.

6.2.2 EASA – Initial Airworthiness

EASA is the primary certification authority for aircraft registered in the EU and other countries where EASA rules are in force. The certification requirements for aircraft and the procedures for obtaining certification approvals are set out in great detail through Regulation (EC) 748/2012 and its Annex I, entitled Part 21. To be able to grant a type certificate and a certificate of airworthiness for individual products, it is necessary to meet the standards of airworthiness issued by EASA as a non-binding Certification Specifications setting out the certification basis. For products such as eVTOL-type (unmanned) aerial systems intentioned for the UAM concept, the closest EASA certification specifications are the following:

- CS-23 – Certification Specifications for Normal-Category Airplanes; and
- CS-27 – Certification Specifications for Small Rotorcraft.

Due to the reasons already mentioned in the very introduction to this chapter, the possibility of applying these CSs to eVTOL aircraft is very unclear due to the dilemma of what such aircraft actually are. Many of the eVTOL aircraft concepts being developed are based on traditional forward-flying airplanes, which have been supplied with the ability to take-off and land vertically. On the contrary, many eVTOL concepts, which are primarily developed for vertical take-off and landing capability and, with their appearance and flight characteristics are a sort of large drones, are also capable of conventional take-off and landing as traditional airplanes. The moment of impossibility of attributing a clear characteristic in terms of a traditional airplane vs. a rotorcraft to this type of aircraft urged EASA to start thinking about the position of eVTOL aircraft in the current robust certification requirements system and to come up with a solution that would allow these new innovative machines to enter the market without compromising the high level of safety standard which aviation has reached through its development over the years. The first result of these efforts was the publication of the document *'Special Condition for small-category VTOL aircraft'* in July 2019. Before analyzing the certification options, which have been opened up by the publication of this document, it is necessary to provide a definition of special conditions as set out by Part 21 in the paragraph '21.A.16B Special conditions':

> *(a) The Agency shall prescribe special detailed technical specifications, named special conditions, for a product, if the related airworthiness code does not contain adequate or appropriate safety standards for the product, because:*
>
> 1. *the product has novel or unusual design features relative to the design practices on which the applicable airworthiness code is based; or*
> 2. *the intended use of the product is unconventional; or*
> 3. *experience from other similar products in service or products having similar design features, has shown that unsafe conditions may develop.*
>
> *(b) The special conditions contain such safety standards as the Agency finds necessary to establish a level of safety equivalent to that established in the applicable airworthiness code.*

This case is in principle covered in particular by point *(a).1* underlining the novel or unusual design which eVTOL aircraft undoubtedly have. In the statement of issue, EASA states that the reason for the elaboration of special conditions for VTOL aircraft was the number of requests for the type certification of VTOL aircraft the Agency received, and which differ from conventional rotorcraft or fixed-wing airplanes. Applying either the certification specifications for airplane or for rotorcraft, depending on whether they are rather an airplane or rather a rotorcraft, with adding certain modifications would not ensure equal treatment according to EASA as it could favor some configurations of aircraft and therefore prevent innovative concepts from fair competition on the market. The special conditions have been developed as a complete set of dedicated technical specifications in the absence of certification specifications for the type certifications of this type of products. The document addresses the unique characteristics of these products and prescribes airworthiness standards for the issuance of the type certificate, and changes to this type certificate, for a person-carrying VTOL aircraft in the small category, with lift/thrust units used to generate powered lift and control. These VTOL Special Conditions were developed based on CS-23 Amendment 5 (which is largely harmonized with the FAA Part 23) integrating elements of CS-27, mainly in order to use objective-based requirements which provide the necessary flexibility for certifying innovative concepts [57].

Such an approach will enable EASA to consider all vehicles with a Certification Basis based on the VTOL Special Condition as 'Special Category' aircraft which will further provide greater flexibility in the development of operational regulatory framework. The distinction of eVTOL aircraft from conventional airplanes is based on the VTOL capability of the aircraft while the distinction from conventional rotorcraft is based on the use of distributed propulsion, specifically when more than two lift/thrust units are used to provide lift during vertical take-off and landing. The small-category VTOL means that the following design limitations must be met [57]:

- a passenger seating configuration of 9 or less passengers; and
- a maximum certified take-off mass of 3 175 kg or less.

In addition, there are two certification categories of eVTOLs introduced in this special condition, which are linked to the intended type of operations – **'Basic'** and **'Enhanced'**. One of the differences between the two mentioned categories is that the 'basic' category of VTOL can only be operated outside congested areas and only private transportation is allowed. 'Enhanced' category is linked to the highest safety levels in terms of protection to third parties, thus it can be operated over congested areas and conduct commercial air transport of passengers. The category 'basic' has to meet controlled emergency landing requirements in a similar manner to a controlled glide or autorotation, whereas the category 'enhanced' has to meet requirements for continued safe flight and landing, and be able to continue to the original intended destination or a suitable alternate vertiport after failure. This is inherently linked to the two concepts of operation that are considered in this special condition [57]:

- high-density deployment of urban on-demand passenger commercial air transport for intermodal connections; and
- high-density deployment of urban and inter-urban, on-demand passenger commercial air transport.

The document further describes in relative detail the individual requirements, broken down in a standard way according to operational aspects into individual subparts to meet the established safety and design objectives. In particular, it covers the general part, which describes the applicability of these special conditions, and the categorization of operations, and subsequently the subparts dealing with flight, structures, design and construction, lift/thrust system installation, system equipment, and flight crew interface and other information. This document should serve as an overview of the airworthiness standards required to enable the applicant to be issued with a VTOL aircraft type-certificate. It should be added that currently the UAS exceeding 150 kg (in the 'certified' category) is not yet certified for civil use in the world. This option will still require a lot of joint efforts, but paving the way for VTOL aircraft certification so far through EASA Special Condition marks a significant step towards it.

To meet the required safety and design objectives set out in the Special Condition for small-category VTOL aircraft document, the applicant must comply with the individual airworthiness standards listed. The next step in enabling compliance was the publication of the *'Proposed Means of Compliance with the Special Condition VTOL'* in May 2020, which was published in response to many requests from applicants for clarification of EASA's interpretation of the objectives and possibilities of how to demonstrate compliance with them.

EASA states that in the preparation of these means of compliance (MOCs) it followed principles to provide sufficient flexibility to address different architectures and design concepts, although it is acknowledged that all possible cases cannot be considered in these MOCs and alternatives can be proposed by applicants to address some particular design features. It is also recognized that the knowledge in certification of these new products will be gained during the certification itself and their entry into service, thus the subsequent better insight into the characteristics might result in modifications of certain elements of these MOCs [58].

It should also be noted that although the document containing the MOCs is relatively extensive, it is not comprehensive as it primarily “concerns subjects that are considered to drive basic design choices and have a higher safety impact on the overall VTOL aircraft architecture”. Proposed MOCs for VTOLs also include references to AMC and GM to CS-23 and CS-27 regulations, but also to other relevant certification specifications, which all should be considered along the way. Proposed Means of Compliance with the

Special Condition VTOL was in the process of commenting until the end of July 2020, thus it cannot be considered as the final version.

The publication of these documents represents an important step towards the future enabling of the deployment of the Urban Air Mobility concept. It is also proof that EASA envisages the implementation of the UAM concept and the corresponding on-demand transportation services and, ultimately, the operation of UAS in the 'certified' category in the future. Along with the development of new technologies, gaining experience in the certification of these products so far through the special condition VTOL, EASA will gain additional knowledge that will help improve airworthiness standards for these new products. It can be expected that in the future, the special conditions and proposed means of compliance will become part of the legislative framework by being transformed into standard EASA certification specifications CS-xx. In conclusion, EASA did not choose the application of various currently approved airworthiness standards to new innovative concepts, it chose the path of recognition and creation of a completely new category of aircraft with the development of new airworthiness legislation. The development of future CS-UAS is described in the following chapter.

6.2.3 JARUS

An advisory body which has been established as a voluntary membership entity in order to cooperate on defining and on the implementation of the legislative basis for UAS is called JARUS – Joint Authorities for Rulemaking on Unmanned Systems. JARUS consists of national aviation authorities from 61 countries (August 2019), EASA and EUROCONTROL. In 2015, the so-called Stakeholder Consultation Body also became a supportive component part for JARUS's activities in order to represent stakeholders from the aviation industry. The aim of the guidance materials issued by JARUS is to facilitate each authority to write their own requirements and to avoid duplicate efforts. The organization includes several working groups dealing with various issues of UAS such as flight crew licensing, operations, detection and avoidance, command and control, safety and risk management, concepts of operation and the most important in terms of this thesis – airworthiness [59].

In October 2019, JARUS issued the document CS-UAS which aims at providing recommendations to civil aviation authorities of individual countries to use for their own national legislation, concerning Certification Specifications for UAS. The document represents a sum of the best practices and procedures used in prior UAS approvals together with the inputs received from the JARUS working group dealing with the issues of airworthiness. The document therefore provides recommendations for design-independent objective requirements as Certification Specifications for UAS in order to be proportionate to the UAS performance and complexity, and the type of operation (instead of weight and propulsion) as part of the reorganization of FAR/CS-23. CS-UAS is primarily intended to be used for the 'certified' category, however, it does not exclude the ‘specific’ category if necessary. The structure of the document corresponds to the structure of EASA documents. It is divided into two main parts – Book I comprised of Objective Requirements on UAS and Book II which is comprised of Guidance Material to the Objective Requirements. Individual sections of the Books start with a general subpart and further continue with aspects such as UAS operation, structures, design and construction, power plant installation, systems and equipment, crew interface and other information, and ancillary systems. All subparts are broken down in detail as a set of detailed individual requirements within the Book I and correspondingly into instructions on how to comply with the requirements in a guidance material within the Book II. In case a means of compliance with a requirement is not part of the guidance material, it must be developed by the applicant, i.e. each applicant can either develop a new airworthiness design standard to comply with CS-UAS or use an accepted standard that already complies with CS-UAS.

CS-UAS sets the following limits for the ‘certified’ category of drones and for the issuance of type certificates (only selected ones are mentioned) [60]:

- MTOM – not to exceed 8618 kg for UAS without VTOL capability and 3175 kg for UAS with VTOL capability;
- human transportation is excluded;
- non-deterministic systems such as artificial intelligence or machine learning are excluded.

From the point of view of the UAM concept operations, these three defined limitations are key and must be resolved for future use. Recreational flying for one's own use may also be part of the UAM concept. However, as far as the concepts of the so-called shared economy and on-demand transportation services based on smart technologies are concerned, human transportation must be included in the type certificates issued for the 'certified' UAS as long as it is sufficiently demonstrated that their use for the transport of persons and commercial use will comply with the requirements imposed by the national aviation authorities. The lower MTOM for UAS with VTOL capability is justified by CS-UAS due to increased risks associated with the hover capability of such an aircraft.

From an economic point of view, it is naturally most efficient to transport a maximum number of passengers with minimum energy consumption. When operating an air taxi within metropolitan areas, but also on medium-range flights, the intention is therefore to be able to transport as many people as possible while maintaining certain standards in terms of comfort and safety of flight. With a higher number of transported persons, i.e. with an increasing payload, the requirements for MTOM will increase as well. This will necessarily have to be reflected in the reassessment of the requirements imposed by the UAS certification specifications on MTOM, especially for UAS with VTOL capability. With the congestion of UAS operations in metropolitan areas in U-space airspace, it will be necessary to implement a reliable collision avoidance system to prevent collisions between aircraft with obstacles and aircraft with each other. Artificial intelligence and machine learning will play a key role in the issue. As already mentioned, developments in this area are advancing rapidly and the most problematic matter so far seems to be the legal aspect of autonomous operation in terms of assigned liability for possible damage to third parties. CS-UAS so far excludes these so-called non-deterministic systems from operation. However, the document itself states that these systems will require additional requirements in addition to the CS-UAS to address the unique items associated with such technology.

The document leaves open space for the future incorporation of amended or supplemented requirements. The article on airworthiness design standards states that the applicant for a type certificate must comply with CS-UAS by meeting established standards approved by the national aviation authority. However, the applicant may propose alternative airworthiness design standards (certification specifications), which must be approved by the NAA. The alternative ADS must then contain the detailed requirements intended to meet the requirements for a specific UAS design, it must be clear how compliance with each requirement is achieved through specific instructions and, if the method of compliance is not clear, it must also include a set of related AMC. JARUS envisages the transport of people and the use of non-deterministic systems in the future UAS operations. Annexes C and D are reserved in the structure of the CS-UAS document, which will address these aspects.

CS-UAS does not cover the differences in certification or operational requirements for VMC and IMC operations. The question has been resolved with the Civil Aviation Authority of the Czech Republic, but it was neither able to comment on the difference in final UAS requirements with certainty. As part of setting up the certification process, there are still ongoing debates and discussions, and more options are being considered. One is that, with visibility during VFR flights, the means of avoiding the surrounding traffic may not be necessary for the operation, in parallel with the operation and equipment of the VFR and IFR aircraft. If eVTOL UA will be operated as part of the metropolitan mobility in U-space airspace, their operation will take place in the airspace blocks between sUAS operations and ATM operations at a height of approximately 1000-5000 ft AGL (for transportation within the city and the immediate vicinity rather at the lower limit of the given range). It is therefore assumed that most flights will take place in VMC. Nevertheless, the intention of the providers of these services will be to expand their use worldwide so that it is not limited merely to densely populated areas located mostly on the coasts of the continents, but also to cities or urban areas in various inland locations and at different altitudes, often with unstable, fast-changing weather conditions. A certification requirement for airworthiness in the IMC will therefore be necessary. Detect/Sense and avoid technology will be essential especially in airspace with heavy traffic and operations in close proximity to buildings and other obstacles, but also in medium-range operations at higher altitudes along with a classic ATM. Thus, as far as the type certificate and the certificate of airworthiness are concerned, the requirements will not contain any differences regarding this matter. The operational requirements may vary depending on current conditions, but the certification requirements will be the same for all 'certified' UA in order to be capable of operation at all conditions.

6.3 National legislation

6.3.1 Comparison of national legislative frameworks

Another part of the analysis and elaboration of proposals for UAS certification options in the 'certified' category in national legislative frameworks is the comparison of the legislative frameworks themselves, especially from the point of view of enabling operation of UAS exceeding 150 kg, thus weight limits, categories of UAS and any other requirements and conditions which are to be met. The comparison of legislation is based on the JARUS comprehensive database of legislative requirements. The database is not a part of this diploma thesis due to the fact that it was created mainly for the needs of the development of legislation for UAS in the categories 'open' and 'specific', but its partial content can be used as an overview for the 'certified' category.

JARUS MSs whose national legislation regarding UAS applies a limit lower than 150 kg or a different weight limit are as follows: Germany (25 kg), Italy (25 kg), Lithuania (25 kg), Portugal (25 kg unless authorized), Slovakia (25 kg, higher weights only with an approval from the NAA), United Arab Emirates (25 kg) and USA (generally also 25 kg or 55 lbs. but exemptions are possible).

JARUS MSs whose national legislation regarding UAS applies a weight limit of 150 kg are as follows: Austria, Belgium, Czech Republic (exemptions are possible), Croatia, Finland, France, Ireland, Latvia, Malta, Netherlands, Poland, Romania, Slovenia, Spain, Switzerland, United Kingdom.

To summarize, JARUS MSs whose national legislation regarding UAS does not apply a weight limit to the UAS, or apply such a weight limit that allows the possibility of operation of UAS exceeding 150 kg under certain conditions and also certification under certain special conditions, are:

- Australia,
- Czech Republic,
- Israel,
- Portugal,
- Qatar,
- South Africa,
- Turkey, and
- USA.

Selected legislative aspects of operation in countries allowing the operation and the certification of UAS exceeding 150 kg under certain special conditions are described in more detail in the following Table 9. It should be noted that the list of countries may be expanded, together with the response of countries to the need to develop new legislation for the UAS. The list in this chapter is valid at the time of creating this thesis.

Table 9 – Comparison of selected national legislation framework requirements

Country	Categories of UAS	Certificate of Airworthiness	Operating limitations for UAS over 150 kg
Australia	< 2 kg 2 < 25 kg 25 < 150 kg 150 kg +	UAS exceeding 150 kg can use an experimental or limited airworthiness process	Specified individually by the NAA
Czech Republic	0,91 kg 7 kg 20 kg experimental aircraft have unlimited MTOM	Currently not possible	Specified individually by the NAA
Israel	Up to 15 kg 15 – 2000 kg	Experimental CofA Special CofA for unmanned systems	According to domestic AIP Only over unpopulated areas
Portugal	25 kg > 25 kg	Currently not possible	Specified individually by the NAA
Qatar	A – 'open' (below 25 kg) B – 'specific' C – 'certified'	Mandatory for the C category	According to domestic AIP
South Africa	1,5 kg 7 kg 20 kg 150 kg > 150 kg	RPAS Letter of Approval	Not specified, the NAA approaches individually
Turkey	**Technical Categories:** 500 g – 4 kg 4 kg – 25 kg 25 kg – 150 kg > 150 kg **Operational Categories:** Hobby/Recreational Specific/Commercial Certified	Mandatory for the category exceeding 150 kg	Standard requirements on vertical and lateral distance limits for RPAS, approval is required from the NAA outside standard conditions
USA	UAS up to 55 lbs. can be flown by following the requirements in 14 CFR part 107 or by obtaining an appropriate waiver; Flying a UAS exceeding 55 lbs., the existing Section 333 exemption process must be used, or an appropriate airworthiness certificate must be obtained	Not required up to 55 lbs.	May not operate directly over a person who is not directly participating in the operation of the UAS unless that person is under a covered structure or inside a stationary vehicle. Daylight only operations. Civil twilight only with approved anti-collision lighting. Night operations may be approved with a waiver. Operations in Class B, C, D, and E airspace require prior ATC authorization, operations in Class G do not. No operations from a moving aircraft are allowed. Operations from a moving vehicle only over sparsely populated area.

Source: JARUS

Based on the above short comparison of selected requirements, it is possible to notice considerable inconsistency and in some cases also ambiguity of the rules. Although some countries have established categories of UAS in their legislation, which include UAS exceeding 150 kg, either in terms of weight or in terms of type of operation ('certified' category), their operation is often limited, or its possibilities are not sufficiently clarified in the regulations within the national legislation, as the development of the UAS within the UAM concept concerns only a limited group of countries so far. Some countries claim to require a Certificate of Airworthiness for UAS exceeding 150 kg, however, the method of its obtaining has not been specified or even created. This is mainly due to the fact that this area of aviation is only at an early stage of development, while the legislative framework for the operation of UAM vehicles has not yet been adapted, given that until recently the national legislative frameworks have focused mainly on the operation of "conventional" small RPAS-type UASs with the RPS control system.

Only the harmonization of regulations at the transnational level, which will be gradually applied to the legislative frameworks of individual states, can help get out of this situation, while states will be able to set additional requirements either for operation or for UAS certification itself. Regulatory harmonization is currently being addressed at international level through EASA and FAA activities and initiatives together with major market players such as Australia, Canada, Brazil, or China to reorganize certification regulations through a unified approach in order to eliminate redundant activities. The most common and at the same time the only possibility of certification of UAS intended for the UAM system is the use of currently valid regulations for general aviation, for which either every single requirement is met, or many exemptions are granted based on the individual assessment from NAAs. As a result, the certification of these UASs is approached exclusively individually. There does not currently exist a harmonized certification process for UAS exceeding 150 kg (in the 'certified' category), which is also confirmed by the opinion of the Civil Aviation Authority of the Czech Republic from May 2020, which states: *"Currently, there is no UAS in the 'certified' category certified for operation in a civilian use in the world. There are only vehicles that are at a certain stage of certification or setting requirements."*

6.3.2 Federal Aviation Administration

The CFR as an administrative law is part of the legal system of the United States of America. Aviation law is defined in Title 14 – Aeronautics and Space and subsequently by its individual Parts, which deal with various areas of aviation law. The FAA as a regulatory body for civil aviation in the US oversees compliance with Parts 1-199. For the needs of this thesis in terms of certification of UAS, it is necessary to take a closer look at **Part 21 – Certification Procedures for Products and Articles**, which has the same purpose as EASA Part 21 and addresses the procedures for certification of airworthiness of aeronautical products with all its aspects. Type certification and certificate of airworthiness are addressed by individual so-called airworthiness standards whose content and numbering are similar to certification specifications from EASA. Only those are enlisted which are related to UAS exceeding 150 kg [61]:

- Part 23 – Airworthiness Standards: Normal Category Airplanes; and
- Part 27 – Airworthiness Standards: Normal Category Rotorcraft.

The need for certification of aeronautical products is generally based on several assumptions – clarity in terms of expectations from the industry, i.e. what regulators will expect, schedule consciousness, i.e. knowledge of applicants and regulatory bodies about durations and deadlines within the certification process, international harmonization in order for products to be operational across countries, and safety. Regulators also need a workload management due to finite resources in order to be able to meet the actions and deadlines set by the relevant procedures in Part 21 related to demonstrating compliance with defined airworthiness standards.

As mentioned in the introduction to this chapter, the biggest challenge for the certification of eVTOLs as a new aircraft concept (not only in the US) is the establishment of a certification basis. Current rules are strongly focused on design solutions and particular types of aircraft. Part 23 presents airworthiness standards tailored to the needs of fixed-wing airplanes, while Part 27 presents airworthiness standards for rotary aircraft, i.e. for helicopters. However, the new eVTOL aircraft take on many of the features of traditional airplanes, so certain parts of Part 23 are applicable to them, but also many features of rotary aircraft, as they have VTOL capability, and therefore parts of Part 27 are also applicable to them. The FAA has recognized this problem and, in collaboration with EASA and other countries and stakeholders, has set itself the goal of changing these design-focused requirements into a set of industry consensus, performance-based standards, which should open up new opportunities in certifying novel concepts of aircraft such as eVTOLs which are a mixture of products such as fixed wing, rotary wing, engines, and propellers. Part of these efforts was the issuance of amendments to Part 23, in particular Part 23 Amendment 64 which is highly flexible and therefore does not require the creation of a special legislative framework for eVTOLs. Innovations in the certification process should be a response to changes in technologies and business models (especially the development of on-demand transport), for which these regulations are no longer sufficient.

The FAA aims in cooperation with the aforementioned entities to create the so-called single-entry point, also called the Center for Emerging Concepts and Innovation, primarily to encourage stakeholders to engage in discussions with the FAA prior to the actual application for certification, which is a contractual agreement that does not allow for further discussion and retrieval of gaps in the certification process. The information and requirements that applicants address here will help further develop regulations and airworthiness standards while allowing better addressing of gaps in regulations and FAA/EASA policies [65]. The ultimate purpose of such a process is to create a final solution that does not jeopardize the safety of air traffic.

The FAA proclaims that it is currently possible to use Part 21, specifically 21.17 (a) or (b) regulation for certification, which allows for the establishment of certification standards for products. One possibility is to proceed in accordance with 21.17 (a) paragraph, which simply requires the use of standards already established for the product. If the product does not yet have defined standards (which is also the case for UAM eVTOLs) 21.17 (b) may be used as it states: *"For special classes of aircraft, including the engines and propellers installed thereon (e.g., gliders, airships, and other nonconventional aircraft), for which airworthiness standards have not been issued under this subchapter, the applicable requirements will be the portions of those other airworthiness requirements contained in Parts 23, 25, 27, 29, 31, 33, and 35 found by the FAA to be appropriate for the aircraft and applicable to a specific type design, or such airworthiness criteria as the FAA may find provide an equivalent level of safety to those parts."* Thus, 21.17 (b) allows the creation of a regulatory pathway to develop the appropriate standards for such products based on the combination of airworthiness requirements contained in other Parts found by the FAA. Subsequently, cooperation is required within the individual branches of the FAA to develop appropriate standards. Performance-based regulations are therefore a completely new approach, opening up to innovative products such as eVTOL aircraft.

Part 1 of CFR Title 14 contains precise definitions in terms of airplane, rotary aircraft, etc. Based on the Part 1, the FAA treats eVTOLs as a rotorcraft, which is defined as *"a heavier-than-air aircraft that depends principally for its support in flight on the lift generated by one or more rotors" (§1.1 General definitions)*. Since eVTOL does depend on the lift generated by one or more rotors in certain phases of flight, but has many characteristics of a traditional airplane, the FAA is developing special conditions that will place eVTOLs in the new category 'Special Class Rotorcraft'.

In the beginning, when the FAA made efforts to apply classic already defined airworthiness standards to eVTOLs, there were attempts to partially modify the rules for the normal category rotorcraft in Part 27. However, it was found that exemptions or special conditions would have to be applied on every word and every rule set out in the regulation. Based on these findings, the FAA proceeded to the possibility of developing entirely new standards under 21.17 (b) for the special class rotorcraft category, under the special conditions that will be applied to this category. It is mainly the need to meet the requirements in terms of innovative approaches such as electric propulsion, fly-by-wire technology, inability of aircraft to autorotate like traditional rotorcraft, etc. Thus, this policy does not change the nature of the aircraft type, i.e. it is still treated as rotorcraft, but by applying the 21.17 (b) process, more effective cooperation with the applicant in determining the certification basis is possible. The reasons given by the FAA in support of the process under 21.17 (b) instead of 21.17 (a) are as follows [62]:

- approximately only 60% of Part 27 requirements apply to these “special class rotorcraft” employing unique, novel, or unusual design features;
- under 21.17 (a), processing of many special conditions and exemptions would be required, which would result in lengthy administrative process;
- 21.17 (b) allows a streamlined process for developing appropriate certification basis
- 21.17 (b) provides greater public visibility of complete certification basis;
- 21.17 (b) process will achieve the same level of safety.

The FAA further lists some steps in the process of issuing a special condition or an exemption to illustrate its complexity and lengthiness – publishing a Notice of Intent to issue special conditions and receiving comments from the public (the process takes 30-45 days), and reviewing and responding to the received comments; if substantial changes are done to the proposed special conditions, another public notice must be issued and undergo comment process again. If further changes are not substantial, the final special condition is issued. This process concerns one special condition, so it is worth noting that approximately 60% of the requirements set out in Part 27, which are applicable to eVTOL with certain variations, would have to go through such a process. Another benefit is that this process allows to present the complete certification basis to the public, not only to a specific applicant, and thus the whole process is significantly shorter and allows other applicants to act accordingly.

Finally, it can be stated that the certification process for eVTOL aircraft so far proposed by the FAA differs significantly from the EASA approach described more in detail in chapter 6.2.2. While EASA is currently working on the development of entirely new airworthiness standards (certification specifications) based on issued Special Conditions for small eVTOL aircraft and for hybrid and electric propulsion applicable to new eVTOL aircraft, the FAA wants, through a process under Regulation 21.17 (b) and with regard to the highly flexible airworthiness standards prescribed by Part 23 – Amendment 64, provide for a specific certification process involving the fulfillment of selected standards from Parts 23, 25, 27, 29, 31, 33, and 35. This procedure will allow the certification of one eVTOL aircraft as a whole without the need to certify its individual components. There is a consensus among stakeholders and certification authorities around the world (including the FAA itself) that in the future the FAA will develop separate airworthiness standards for eVTOL concepts, but only after further implementation of the UAM concept, and thus after gaining some operational experience. However, despite the different approaches, the ultimate objective is a sufficient level of operational safety, which will be met by this process.

6.3.3 Civil Aviation Authority of the Czech Republic

The Civil Aviation Authority (CAA) of the Czech Republic considers the possibility of certification of the UAS in the 'certified' category to be realistic in the Czech Republic in the future, but in the current situation it does not have an estimate of the time frame. EASA, which is the CAA's superior body, is currently placing the 'certified' category of UAS in the third place among its priorities. However, the CAA states that the 'certified' drones are a condition for enabling operation in the U-space system.

In terms of operational capabilities and airworthiness of UAS over 150 kg / in the 'certified' category, the Czech CAA provided the following opinion: *"The only current option for UAS exceeding 150 kg (in the 'certified' category) in the Czech Republic is to use the available applicable regulations, modified for a specific UAS. The certification base would have to be agreed and the procedures would be established in accordance with either L8/A Aviation Regulation or Part 21."*

The purpose of Regulations (EU) 2019/945 and 2019/947 is to harmonize the approach of EASA MSs to UAS, to unify the categorization of UAS, to establish uniform operational and certification rules, to move towards the implementation of U-space, etc. and, in particular, the harmonization of the different national legislative frameworks, in which the rules for UAS are currently addressed by various appendices, directives and decisions of national aviation authorities, which do not always fit into the standard structure of aviation legislation. These new European regulations are to enter into force on 1 January 2021, setting out a further timetable for harmonizing the rules for UAS in all Member States of the European Union and other EASA-mandated countries. In August 2020, Supplement X of the L2 Aviation Regulation, which sets out the rules for the certification and operation of drones in the airspace of the Czech Republic, is still in force. Due to its generally discussed shortcomings resulting from incompleteness, ambiguity and, above all, outdated rules, an amendment to the Aviation Act is on the agenda in the Czech Republic, which should be a response to the request to clarify the situation and which will set requirements not covered by the EU legislative framework.

In addition, the CAA of the Czech Republic was asked about differences in certification, which will be adopted through an amendment to the Aviation Act, and in general about differences in the approach of the European Union and the Czech Republic to the certification of the 'certified' UAS between legal and natural persons. With regard to that issue, the CAA similarly stated that it was not able to comment on the issue with the currently available information. EASA sets certification and operating rules with different levels of operating restrictions for recreational and commercial operations. It will be possible to use the certified UAS even beyond the usual recreational possibilities, i.e. for commercial use. Commercial use can be operated by both natural and legal persons; therefore, it will always be necessary to assess the type of intended operation and the corresponding UAS.

In conclusion, it can be stated that the overall approach of the Czech Republic / European Union / USA to the certification of 'certified' UAS is quite similar, the differences may be in the possibilities of the given operating restriction taking into account, for example, the characteristics of the landscape and the intended area of operation. In the Czech Republic, for example, it is not possible to allow the use and assurance of the ability to operate over an environment where there is no threat to third parties on land (e.g. desert and sea areas, etc.). In these respects, the certification rules may be stricter or may not include a lower level of operating restrictions.

'Experimental' category of aircraft

The currently valid Czech legislation allows the certification of the so-called individually built aircraft in the category 'experimental' by issuing a Special Certificate of Airworthiness (in Czech the abbreviation ZOLZ is used) according to regulation L8/A – Airworthiness of Aircraft – Procedures. The Civil Aviation Authority of the Czech Republic shall issue such a certificate to aircraft *"for which it has not been possible to demonstrate full compliance with the regulatory basis, with such limitations as will result from non-compliance with the established regulatory basis and which will guarantee an acceptable level of air traffic safety and damage to health or damage to the property of third parties"*. The UAM eVTOL concept is covered by Title 6, in particular paragraph 6.3.1 (a), according to which aircraft intended for *"testing of new concepts, new equipment, new installations, new operating methods or new use of aircraft of an approved type"* are included in the category 'experimental' [63].

As a guide to meeting the requirements of the 'experimental' category of aircraft, the CAA of the Czech Republic has issued a body of advisory documents that provide an overview of the basic requirements of aircraft building regulations that must be met in order for an experimental aircraft to be airworthy. It should be noted that the manuals do not replace the specific building code to which the compliance with airworthiness requirements applies. In addition to the aviation regulations L8 and L8/A, the following advisory circulars issued by the CAA of the Czech Republic in the Czech language are of particular interest to the applicant or the builder of such an aircraft [64]:

- PO/TI – 20-1 – Manual for individual aircraft construction;
- PO/TI – L8/A.2.7.6.A – Airworthiness of individually built aircraft and its components; and
- PO/TI – L8/A.2.7.6.a).A – Issuance of a Special Certificate of Airworthiness (ZOLZ) for the Experimental category.

The last of these documents contains instructions for submitting the application, demonstration of the aircraft for ground inspection and test flight, and for the Issuance of the ZOLZ itself, stating the relevant deadlines and other requirements of the relevant regulations, as well as instructions with administrative fees.

An experimental aircraft is an aircraft built by a non-certified manufacturer for private purposes and cannot be used for commercial purposes such as transportation of passengers for remuneration. The main advantages of experimental aircraft are the wider possibilities in the field of innovation in the introduction of new ways to fly, and thus also in the creation of new concepts, as well as much greater affordability. The construction of a certified aircraft is many times more expensive due to the costs associated with the administration and certification process, which consists of thousands of hours of test flights and separate tests of various components and equipment. In addition, for certified aircraft, any minor change in design must be recertified by the Authority, incurring additional costs for test flights and related administration. In the case of an experimental aircraft, these costs are eliminated, but their disadvantage is the lower market value consisting in the absence of a sufficiently tested level of safety and also in the fact that the manufacturer is also their "test pilot". The reason why manufacturers approach the introduction of experimental aircraft is mainly lower costs, but also the inability to meet all the established certification requirements imposed by the legislation framework currently in force. For example, in the approach to the use of lower-cost avionics in the form of tablets and other non-certified displays, which, although not certified, might often be fully sufficient for the needs of the operator.

On the other hand, certified aircraft have a much higher value on the market, mainly due to the fact that they are subject to stricter requirements for airworthiness. These aircraft go through a lengthy certification process in the form of test flights. The result is a better safety record, lower probability of accidents or incidents, etc. As a result of lengthy and costly product recertification procedures, traditional manufacturers in the field of general aviation approach changes in construction, design and the technologies used much more cautiously and less frequently. For these reasons, the use of old airframe designs and technologies often appears to be more efficient, both because they are reliably verified over years of operation and because recertification costs often exceed the expected benefits. Nevertheless, currently, the 'experimental' category of aircraft, despite the CAA's stating that the certification of UAS exceeding 150 kg according to L8 Aviation Regulation or EASA Part 21 could be possible under certain conditions, is the only and currently the most accessible option in the Czech Republic to partially certify a UAM eVTOL. Other future possibilities for eVTOLs certification in the Czech Republic will be strongly linked to the development of legislation at the EASA level.

6.4 Minimum requirements and instructions for the certification process

As described above, the FAA allows certification to proceed through the use of Part 21, specifically 21.17 (a), according to which standards already established for products can be used. Since eVTOL is a new concept for which standards have not yet been established, Part 21.17 (b) will be applied and a new regulatory pathway will be created combining the requirements of several FAA Parts. The key moment for applicants is to get engaged in discussions with the FAA through the Center for Emerging Concepts and Innovation, which should be contacted well prior to submitting an official application for certification in order to find gaps in the certification process and identify specific needs of applicants. One of the divisions of the Aircraft Certification Service, which is part of the FAA, and is called the Policy and Innovation Division, will serve as the point of contact for the applicants. The highly flexible Part 23 Amendment 64 will allow the applicant directly in consultations with the FAA to find the most suitable way to meet the individually selected requirements from various FAA Parts within the certification process. So far, this method is based on a very individual approach, but its advantage is that the aircraft becomes certified as a whole, without the need to certify its individual parts. This approach will allow the FAA to gain experience and knowledge from the individual applications in the coming years and should result in the development of uniform certification standards for eVTOL aircraft once the UAM concept becomes more mature. Given the relatively rapid development of eVTOL aircraft in recent years, to which the legislative framework fails to respond in a timely manner, such an approach can mark a significant step towards the creation of new airworthiness standards. The creation of uniform airworthiness standards will be necessary with the development of the UAM concept, but still it can be expected to be a long way off. However, the advantage remains that, although the whole certification process may seem to be lengthy, it is still much shorter than the approach with exemptions for individual requirements of already established standards according to the 21.17 (a) path, but in particular, at the end of the day the certification of eVTOL aircraft is possible.

From the point of view of the applicant for eVTOL certification in the Czech Republic, the closer look must be taken on the certification options of eVTOLs as currently set by EASA. In case the applicant does not wish to certify an eVTOL aircraft in the 'experimental' category in the Czech Republic, the Czech CAA needs to proceed in accordance with the EASA rules. EASA chose an approach towards the eVTOL certification which is similar to the FAA's, consisting of gaining experience and knowledge for the later establishment of uniform certification specifications for eVTOL UA in the 'certified' category, however, with the use of different tools. While the FAA approaches the certification of eVTOLs individually, according to the currently valid FAA Parts, and uniform airworthiness standards are a matter of more significant development and implementation of the UAM concept, EASA plans to create separate uniform certification specifications for eVTOL UA in the foreseeable future while the 'Special Conditions VTOL' document (hereinafter referred to as SC-VTOL) is only intended as a temporary solution for the certification of this type of aircraft.

SC-VTOL sets a certification basis for eVTOL aircraft classifying them in the 'special category'. The applicable limits are taken from CS-27 for small rotorcraft – passenger seating configuration is 9 or less passengers and MTOM is 3 175 kg. As described in the previous subchapters, SC-VTOL introduces two categories of certification – 'basic' and 'enhanced' – according to the intended type of operations, the 'enhanced' category will be used for aircraft within the UAM concept. It is necessary to meet the detailed requirements that SC-VTOL divides according to categories into subparts A – G, where they are marked with a unified numbering *VTOL.XXXX*. SC-VTOL does not refer to other EASA CSs anywhere in the text, which makes it rather a clear and a comprehensive material, although it does not include means of compliance to meet the established minimum requirements.

The document 'Proposed Means of Compliance with the SC-VTOL' (hereinafter referred to as MOC SC-VTOL) serves to meet the requirements set by the SC-VTOL. To meet the requirements defined in Subpart A (General) and Subpart B (Flight), the MOC SC-VTOL and its corresponding parts are sufficient, and define in detail the fulfillment of each requirement set in SC-VTOL. The guidance on compliance with the requirements set in Subpart C (Structures), Subpart D (Design and Construction) and Subpart E (Lift/Thrust System Installation) is again described in the MOC SC-VTOL document, with some clauses referring to sections in CS-23 Amdt. 4, CS-27 Amdt. 6, CS-25 Amdt. 24 and CS-29 Amdt.7. The only part of SC-VTOL that has not yet had a defined means of compliance is the Subpart G, which concerns the Flight Crew Interface and Other Information. The means of compliance for the Subpart G are expected to arrive in later versions of the document after some experience in the certification process is gained and gaps in the currently available procedures are identified based on comments from applicants and stakeholders. MOC SC-VTOL document represents only a summary of the proposed means of compliance, its final version will be released later after the termination of the comment procedure. EASA expects that individual MOCs may change over time, or completely new ones may be issued with an increase in experience and knowledge gained in the certification process.

This subchapter aims to summarize the current possibilities of certification of electric VTOL aircraft in terms of meeting the minimum requirements and also provide the applicant with instructions on how to go through the certification process, at the end of which the certification of unconventional and novelty eVTOL aircraft is achieved by granting a type-certificate. In the European Union under EASA rules, the minimum requirements on UAS are established in detail in the SC-VTOL document, the certification procedure to meet the minimum requirements will then be based on the MOC SC-VTOL document. In the United States for now, minimum requirements will be established individually by the FAA based on the performance-based principle and design of the particular eVTOL applying for the certification process by selecting the individual requirements from the already established FAA Parts. Instructions on how to meet the selected requirements will be established accordingly again on an individual basis. This chapter of the thesis can serve applicants for eVTOL type-certificate as a comprehensive overview of information about currently available options for completing the certification process.

Discussion

This master's thesis aimed to shed a little more light on the issue of current possibilities of operation of unmanned aerial systems exceeding 150 kg, which is also pointed out by its rather extensive topic name "current operational possibilities". As stated in the thesis itself, the concept of flying machines that people could use for transport, i.e. a kind of "flying cars", is nothing new and is the motif of many sci-fi novels of the 20th century. The era of progress that brought the rapid technological development in the fields of materials engineering, electronics, IT, smart technologies, and the expansion of drone use in the last decade has made it possible to gradually transform these ideas from paper into reality. Technological start-ups around the world have begun to come up with the concept of a machine that takes over the construction of a light aircraft with the addition of several elements from drones, and allows the transport of people, cargo, mail, etc. Lightweight, carbon and composite materials allow these machines to maintain their minimum possible weight at the maximum possible load capacity at their respective dimensions, which allows their relatively efficient operation.

In the context of climate change, particular emphasis is placed on the ecological sustainability of mobility. In line with sustainability, these new machines are commonly designed with electric propulsion, possibly in combination with modern low-consumption internal-combustion engines with a minimized carbon footprint. Significant technological advances have also been made in the field of electrochemical cells, solar cells and hybrid or fully electric propulsion, and given the use of green electricity, it can be a good answer to sustainability requirements. The intention is also to reduce the burden on land transport infrastructure, which, especially in densely populated areas, ceases to manage traffic volumes and satisfy the transport needs of the population. In the context of this thesis, the term unmanned aircraft should be used, but in the initial phase of their implementation, piloted flights are considered, which will proceed to an autonomous mode only with the development of artificial intelligence, and especially when national aviation legislative frameworks allow it. Although autonomous aircraft operation is expected in the future, it is not currently on the agenda and the aviation authorities are only marginally interested in for the time being. Aircraft intended for the concept of urban air mobility are nowadays referred to by the term eVTOL aircraft – an aircraft with vertical take-off and landing with electric propulsion. In recent years, the interest and popularity of the concept of shared economy and on-demand services, which have become a common part of our lives in the form of applications in smartphones, has increased. This will make it possible in the future to use eVTOL aircraft for satisfying transport needs in metropolitan areas, but also for longer distances within the Urban Air Mobility concept.

However, the development of this new aircraft concept has been so rapid that the current aviation system, with all its rules and legislative requirements, is unable to respond in a timely manner. The paradox is that although it is now possible to buy an eVTOL aircraft, the possibilities of its operation are almost non-existent or very limited. A major topic in this area is the integration of eVTOL aircraft into the current air traffic control system. Today, EASA is working on the development of the U-space system, which should in the future enable the integration of drones into normal air traffic while maintaining maximum safety standards. The last adopted regulations ceased to categorize drones based on their weight and began to categorize them based on their intended use. Three categories of operation have been identified, which are supported by several European regulations. The aircraft, which are the subject of this master's thesis, are included in the so-called certified category, which EASA now places in the third place among its priorities, given that their expansion is still minimal compared to the smaller drones whose operation falls into the two lower categories. The U-space airspace, which is to become the airspace for the operation of drones in Europe, considers a certified category of drones in the future, but it is still a distant state. The thesis therefore presents a proposal for the partial extension of the U-space system by some specific services, or the extension of already intended services, so that the U-space system is able to accommodate the certified category of operation. This concept is largely based on the ideas of a specific design by Embraer, which presented the concept of the future operation of the Urban Air Mobility concept and the possibilities of the future operation of certified drones within the urban airspace for common transport needs in its White Plan. Although the integration of eVTOL aircraft and UAS into the air traffic management system was not an explicit part of the assignment of the thesis, it is certainly crucial for future development and can therefore be included in the analysis of current operational possibilities. For the future development, it will certainly be beneficial to elaborate independent academic theses on the topic of integration of certified UAS into today's ATM system, which will deal in depth only specifically with this topic.

As mentioned above, an important topic within the development of urban air mobility is the issue of autonomous flying, which is very extensive and also deserves its own academic theses and scientific studies. In this thesis, the issue is described mainly analytically, with emphasis on the need to pay attention to ethical questions that come with the development of artificial intelligence, and the need to maintain aviation safety and trustworthiness in these technologies. One of the most problematic aspects of autonomous flying, apart from the technological challenges themselves, will be the legal aspect related to assigning liability for any damage caused. It will be necessary to focus on the extent to which the aircraft manufacturer will be liable, the extent to which the operator will be liable, the extent to which third parties that will interfere with the operation will be liable and the extent to which society will be satisfied with assigning liability to force majeure. The elaboration of academic theses on this topic will be necessary and very welcome.

The key task in the master's thesis was to analyze the possibilities of certification of unmanned aerial systems so that they can become part of normal air traffic. In order for an aircraft to fly freely in the airspace above land and people, it must meet strict airworthiness standards. The key to enabling the operation is the issuance of a type-certificate for an aircraft type and a certificate of airworthiness certifying that a particular aircraft is in conformity with the approved type. For completeness of information, it must be added that the type certificate is also granted to engines and propellers. Unmanned aircraft face a huge obstacle here. Today's robust system of certification requirements, which is used in aviation practically all over the world, was created over a long period of time and has responded to various events and milestones in aviation development. An important finding from the elaboration of this thesis is the fact that the current system of certification requirements distinguishes at the highest level basically only an airplane and a helicopter. Virtually any other machine that is neither an airplane nor a helicopter is not standardly certifiable for passenger transportation in today's conditions. The eVTOL-type (unmanned) aircraft system contains many elements of traditional airplanes, but also elements of helicopters. It is distinguished from a traditional airplane by the creation of lift by thrust/lift units in addition to the wings, some types also allow hovering mode, and from a traditional helicopter by the fact that it uses more than two units for creating thrust/lift and often allows conventional take-off and landing. Thus, it represents a kind of hybrid between an airplane and a helicopter. With increasing requests for the certification of eVTOL aircraft, aviation authorities had to respond by creating new certification requirements that instead of the design-orientation would be based on aircraft performance characteristics. During the elaboration of the thesis, it was found that the American FAA and the European EASA are furthest in their efforts. Today, the FAA allows the certification of such machines under one specific clause in the FAA Part 21 standard, which allows the creation of an airworthiness standard tailored to a particular aircraft and applicant by selectively selecting specific requirements from different FAA Parts. This approach is very individualistic, but its advantage is that the aircraft is ultimately certifiable as a whole without the need to certify its individual components. However, it is appropriate for the applicant to discuss the requirements and characteristics of the aircraft with the FAA prior to submitting an official application for certification, in order to identify gaps in legislation or other specifics that may arise in the process in advance. EASA, on the other hand, argues that combining requirements from different certification specifications designed separately for aircraft and helicopters would not be the right practice, as it could favor certain specific types of configurations and thus jeopardize market competitiveness. Therefore, a special category of VTOL aircraft, to which these machines belong today, was created at the EASA level, and specific certification requirements were presented to it, according to which these aircraft can be certified today. In addition to the established requirements, detailed means of compliance have been issued as well so that manufacturers and applicants know what requirements they have to meet and how.

The master's thesis thus describes the current certification options for eVTOL aircraft in Europe and America. Along with the description, a proposal was prepared, which serve as a guide for applicants for certification on how to go through the certification process, the successful result of which will be the granting of a type-certificate. Given that the thesis was elaborated in collaboration with the Czech developer of VTOL aircraft, the company Zuri, the procedure was also described from the point of view of the applicant in the Czech Republic, which in addition to EASA rules also allows certification of eVTOL aircraft in experimental category with significantly limited operation. However, the output from this section is considerably limited by the still very limited certification capabilities and ambiguity in the approach to certification, even between such robust entities as EASA and the FAA. Today, both of these authorities allow the certification of an unmanned aircraft in a certified category on the basis of slightly different procedures, the common feature of which is a non-standard, specific approach. So far, they represent only a temporary method with the inclusion of these aircraft in a special category. However, EASA and the FAA agree that cooperation and information exchange are well established and plan to create uniform rules for this new aviation development branch in the future, after gaining sufficient experience from certification processes.

Conclusions

This master's thesis described the issue of unmanned aircraft exceeding 150 kg, respectively unmanned aircraft in the certified category of operation. The first chapter of the master's thesis deals with the inclusion of certified-category unmanned aircraft in the legislative framework of the European Union, describes the development of this legislative framework and the division of unmanned aircraft into individual categories. It also describes certified unmanned aircraft in the context of Czech legislation. The second chapter of the thesis presents the idea of the concept of Urban Air Mobility, which aims to transfer the fulfillment of part of the transport needs of the population to airspace with emphasis on environmental sustainability and relieving land transport infrastructure, in the context of smart technology development and demand for the so-called on-demand transportation services. Selected projects of (unmanned) VTOL aircraft, which are undergoing development, are also described. The third chapter discusses some of the risks associated with the operation of large drones, which is a more general part of the thesis, where the idea of the need for regulation in aviation is discussed. It also touches on the legal aspect of autonomous operation and test sites, which are an integral part of future development due to the fact that they represent places where test flights of aircraft, which are a precondition for novelty aircraft certification, are carried out. The fourth chapter is relatively extensive and deals with the possibilities of integrating the certified category of unmanned aircraft into the current air traffic management system. It contains the official vision of EASA, which is the development of the U-space system within the Single European Sky program that is to integrate unmanned aircraft into the airspace. Given that EASA only deals with the certified category of unmanned aircraft as the third priority, a proposal was made to extend the U-space system with certain services in order to enable the future integration of the certified category into normal operation. The proposed concept could serve as inspiration for the elaboration of an independent academic work on this topic. It has no ambition to represent the final desired state. The fifth chapter of the thesis discusses some of the challenges of deploying autonomous operation in aviation, which will have to be addressed in the future if autonomous operation is to become a reality in the future.

The key part of this thesis is the last chapter, which deals with today's certification options for eVTOL unmanned aircraft, whose incorporation into airworthiness standards is very challenging due to the rigidity of legislative frameworks and their absence of ability to integrate completely new concepts. The aim was to analyze the certification options in terms of national and international legislative frameworks and to propose a certification procedure for (unmanned) eVTOL aircraft according to the current legislation. Both FAA and EASA approach the issue in slightly different ways. The FAA is working to fit the novelty concepts of eVTOL aircraft into the current airworthiness standards and EASA is working to create entirely new certification specifications that will respond flexibly to the new design of these aircraft. There is a consensus that in the future a separate category of aircraft should be created for these novelty machines with the definition of their own requirements and means of compliance. For the time being, both institutions categorize these aircraft into the so-called special category and from the certification processes that will take place in the coming years, they wish to gain experience and knowledge that will allow the creation of separate airworthiness standards. The certification of fully unmanned operation is envisaged by the authorities in the future, but neither at present nor in the near future it will be possible due to the insufficient maturity of artificial intelligence from the point of view of the complex system of air operations and due to the unclear method of attributing liability for damages. It is necessary to state that the ambition of this thesis was to bring a separate proposal for certification, which, however, the current situation of ambiguity of legislative frameworks in such large institutions as EASA and FAA only partially allowed. One of the additional options offered in the Czech Republic is the certification of these aircraft in the experimental category, which allows only the operation limited to private use and testing in designated airspace, not commercial use. Better clarity in the area of certification of new concepts will be preceded by a long development and a lot of discussions between certification authorities and stakeholders. This master's thesis was prepared in cooperation with the Czech developer of the medium-range VTOL aircraft, the company Zuri, with which several proposals and components of the thesis were consulted. Part of the thesis is therefore an appendix in which the reader has the opportunity to get acquainted with the Zuri project in terms of its development history, aspects of the development of the aircraft itself, currently used certification basis to allow operation, test sites and conditions in which test flights take place, and at the end, several use cases are also presented, which illustrate the idea of the intended operation of the aircraft for the sake of clarity given in comparison with conventional aviation.

To return to the essence of the thesis, it is necessary to state that the Achilles heel of this thesis may be the breadth of the chosen topic as the thesis describes the current possibilities of UAS operation extensively without more detailed goals. It touches on the area of current legislation in the field of UAS, describes the concept of Urban Air Mobility, the operational risks and weaknesses associated with the operation of UAS aircraft and also marginally discusses autonomous flying, which is the ultimate goal of the Urban Air Mobility concept. More extensive parts of the thesis contain the integration of certified UAS into air traffic control services and, finally, the certification of aircraft itself. The number of topics covered did not allow to go into more detail with regard to compliance with the already extensive scope of this master's thesis. If, as the author of the thesis, I had the opportunity to address the topic again from the beginning, I would certainly proceed to a narrower focus on only one or a couple of issues, which I would analyze in more depth. The thesis elaborated in such a way could represent a more significant contribution to a specific area of operation of large drones.

However, given that it is still a very young area of aviation, which began to develop to a greater extent only a few years ago, a number of studies and academic works that would address similar issues, is limited. Therefore, the master's thesis does not follow up on any academic works from the past, its basis is mainly European, Czech and American legislative documents and communication with Czech institutions involved in air transport – mainly the Civil Aviation Authority of the Czech Republic and Air Navigation Services of the Czech Republic with their experts. The contribution of the master's thesis can be the clarity of information about current certification options, which will orient the applicant for certification in the issue and will also serve as a comprehensive guide to the procedure. At the same time, it can serve as a springboard for future academic works, which will focus on a selected aspect of the operation of unmanned aircraft in more detail. The basic goal of the thesis was to bring a little more light to the issue of large drones and to raise awareness of the challenges and problems that this new branch of aviation faces today across the spectrum of experts in the field of aviation, but also outside it. Given the detailed description of several areas of unmanned aircraft operation and the presentation of proposals for the integration of UAS into the ATM system and the certification procedure for unmanned aircraft certification, this objective can be considered to be met. It will be possible to follow up on this master's thesis with further academic works and research in various more specific fields.

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Note: The official deadline for the submission of the master's thesis has been postponed to 10 August 2020 due to the ongoing Covid-19 pandemic. In the assignment attached at the beginning of the master's thesis, however, 18 May 2020 remains the official submission date. Regarding the matter, some dates of citations of the following references may be exceeding the submission date set in the assignment.

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Appendix I Presentation of the Zuri project

This master's thesis on the current operational possibilities of UAS exceeding 150 kg (in the 'certified' category) was being elaborated in cooperation with the Czech developer of an UA intended for the operation of an eVTOL air taxi – the company ZURI. As an appendix of this thesis follows a short presentation of the company in terms of its history, the development process of the UA and the services that ZURI plans to provide once the aircraft is eligible for operation. The figures and tables presented in this appendix of the master's thesis were provided by the company ZURI as its own internal material.

History overview

The concept of the aircraft was created in 2017 as an idea of the company's founder in the form of a visual sketch later transformed to a more professional form by an aerospace designer. During 2018, the first model with a two-meter wingspan was created, which enabled to test various flight characteristics and, due to the relatively low costs, helped the rapid progress in development. Also, a five-meter prototype was later created and tested in horizontal mode in the classic forward flight, with the later addition of a vertical take-off and landing system for testing in hover mode. Further development of the concept was made possible by the expansion of the development team supported by the entry of several investors and strategic partners. During May 2019, tests of some components of the prototype began to take place, electric motors, avionics and also batteries for flight were tested, and at the end of 2019, tests were carried out in the aerodynamic tunnel at the Czech Aerospace Research Center [65].

Aircraft development

At the time of the completion phase of this master's thesis, there is an ongoing development of an experimental aircraft, the so-called demonstrator, which in the first phase will be used as a flying wing for testing components in hover mode, while in the second phase it will be upgraded to a full single-seater aircraft [65].

Based on the information provided by the company, it can be summarized that the development has gone from simple to more complex models and the main task of the company is currently the completion and deployment of an unmanned technology demonstrator, which is accompanied by constant testing and debugging of components. The demonstrator is based on the existing ultralight aircraft – Dusty 200 from the company TechProAviation s.r.o. – which is about to be introduced into series production and which is significantly modified to fit the needs of ZURI for the development of the UA, while the development of the empennage section, VTOL system consisting of horizontal propellers and the related development of the control system are underway.

Further development of the final concept will follow the tests of the demonstrator, which is currently in the phase of feasibility study with the processing of design and business analyzes. The prerequisite is the processing of quality market research to determine which services are in the greatest demand on the market. The subject of the research is to determine the parameters such as range, speed, and number of passengers, according to which the aircraft is subsequently designed in terms of construction. Then follow the structural design analyzes such as aerodynamic computation fluid dynamics and strength tests. A simulator for verification of flight characteristics, debugging and testing of the stabilization system is also undergoing the development phase. The company is working on its own computer vision system, which in the first phase aims to prevent the propellers from spinning if there is a person standing in a close proximity to the machine.

Certification basis

Supervision over the development of the demonstrator is held over ZURI by the Civil Aviation Authority of the Czech Republic. The certification basis for the development of the demonstrator is the category 'experimental' (described in more detail in chapter 6.3.3) with the fulfilment of selected requirements according to CS-23 amdt. 4. During the approval of the demonstrator, the CAA requested additional fire resistance tests.

Test site

The general aspect of UA test sites has already been described in more detail in the chapter 3.3. ZURI has signed a coordination agreement with the airport in Milovice, which serves as a company test site and is also approved by the CAA for the tests of the demonstrator. The test area is currently operated by a private flight school, to which it also serves as a public area for sport flying. Activities at Milovice Airport are regulated in particular by the following documents:

- Airport Rules;
- Safety guidelines of the operator of Milovice Airport LKML; and
- VFR manual of the Czech Republic published by ANS of the Czech Republic.

In terms of general conditions, ZURI is under the supervision of the CAA. For each test, a measurement methodology containing the conditions and provision of measurement must be elaborated. The methodology is subject to an approval from the CAA. All activities must be carried out in such a way that air traffic is not disrupted and that other persons and property at the airport are not endangered. A coordination agreement has been concluded between ZURI and the airport operator regulating the conditions of using Milovice Airport for testing purposes and according to which the testing is carried out. The coordination agreement further limits the operating conditions of the tests as follows:

- operation during the day only;
- conditions for VFR flights, without rain or snow precipitation;
- max. wind speed of 5 kn;
- min. temperature of 0 °C.

The following operating conditions are also established to maintain the safety of tests and operations at the airport:

- all test participants must undergo airport operator safety training;
- the aircraft must be anchored to two independent points throughout the duration of the testing;
- a protection safety zone must be established in which the movement of persons during testing will be restricted;
- a fire fighting unit must oversee the entire testing process;
- air traffic at the airport is limited and radio service must be provided;
- the responsible ZURI employee must be available on the radio frequency connection.

The following Figure 12 shows the prescribed dimensional limits of the specified active protection safety zone.

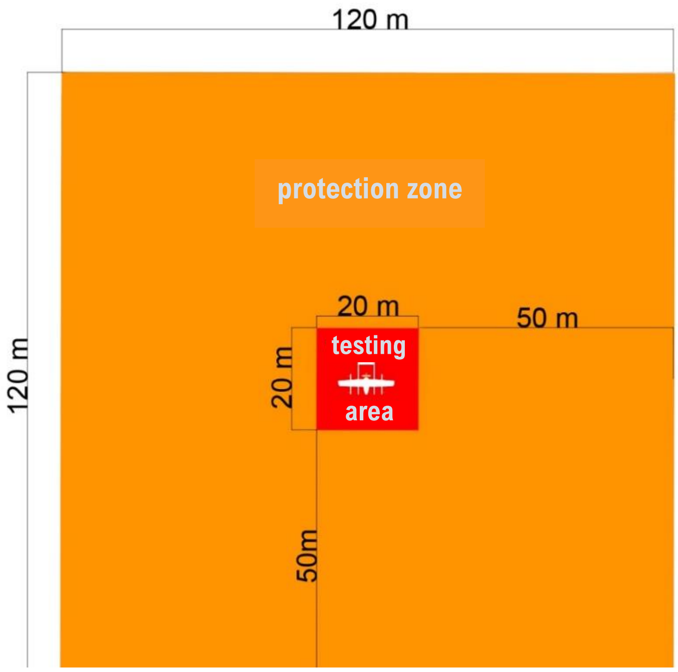


Figure 12 – Dimensional limits of protection safety zone

Use cases

The projects of some of the UASs mentioned in this work (such as EHang or Volocopter) are being developed primarily for urban air mobility within densely populated metropolitan areas and their immediate surroundings. It would be a shame, however, to omit probably the shortest flight ever operated by a jetliner, the flight of People's Viennaline operated between Friedrichshafen and St. Gallen over Lake Constance / Bodensee, which normally lasted 8 minutes and the distance flown was ca. 25 km. With such parameters, the flight essentially met some of the aspects of urban metropolitan mobility flights. It was in operation in 2016 and 2017 and was later canceled for economic reasons. On the other side of the list of extremities in length and duration of flights, at the time of the operation of this short flight, there was an Emirates flight operated between Dubai and Auckland with an average flight time of 16,5 hours covering over 14 200 km [66]. With the arrival of new lighter, and economically and aerodynamically more efficient aircraft at the market, the endurance and range are expected to increase further, as evidenced by, for example, Singapore Airlines' regularly scheduled flight from Newark to Singapore covering almost 16 000 km in 18 hours. Apart from these extremes, it can be summarized that classic jetliners are designed for long range operation on larger domestic, international, and intercontinental flights.

With its 700-kilometer range, ZURI plans to operate medium range flights between cities, and thus represents a kind of a compromise between urban air mobility air taxis operated in urban and surrounding environments and long-range jetliners. The following Figure 13 presents the outputs of the *Business Jet Traveler's 8th Annual Readers' Choice Survey*, which ZURI provided for the needs of this thesis.

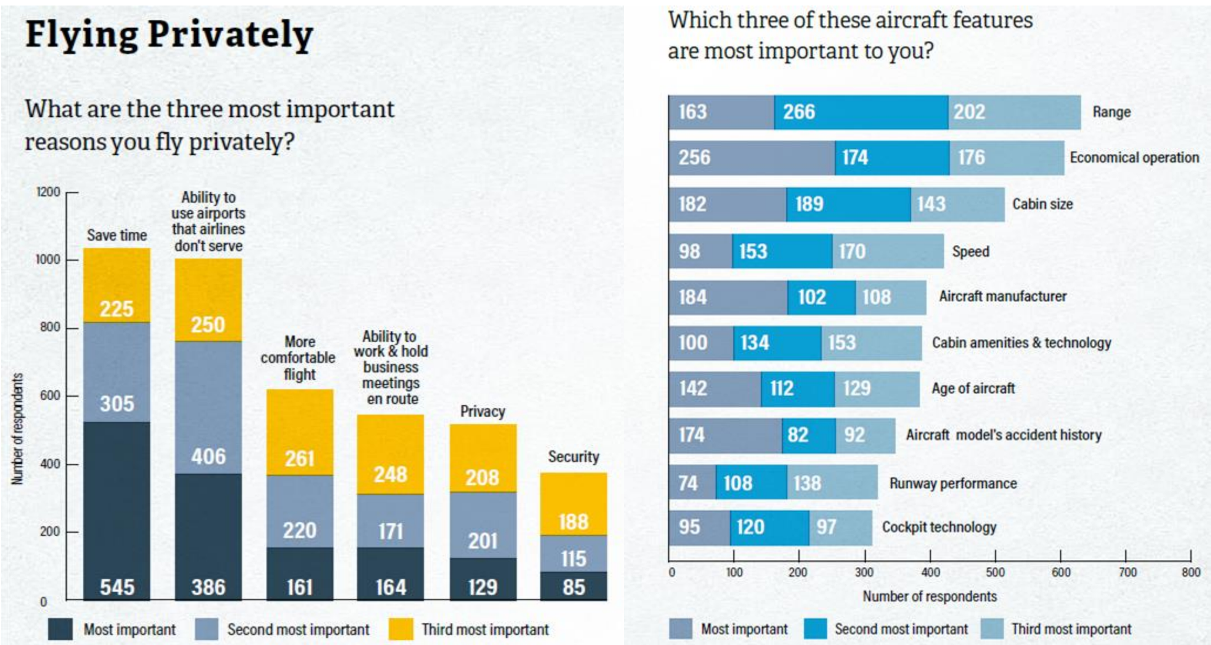


Figure 13 – Business Jet Traveler's 8th Annual Readers' Choice Survey

The graph on the left side of the figure shows that the most important reasons to fly privately for most users is saved time and usability of airports that are not commonly operated by airliners. As a third priority, a relatively large part of the respondents stated the comfortability of flights and the possibility of working or organizing business meetings during flights which again results in saved time. While developing its aircraft, ZURI took these frequently cited reasons into account in order to focus on the businessmen customer segment that uses private jets the most. From the graph on the right of the figure, it is clear that the most important feature of the aircraft used in private flying for potential customers is the economic operation, cabin size and aircraft manufacturer. Customers consider the range to be the second most important feature. In the sum of respondents, however, the range of the aircraft is the most important.

ZURI is designed for three to four people, including the pilot on board in the initial phase, with the maximum possible degree of flight automation. As soon as the certification specifications and related legislation allow for unmanned flights with passengers on board, ZURI envisages a transition to a fully autonomous mode of operation. The range of the aircraft is 700 km, which is suitable, as already mentioned, for medium range flights. Thanks to the design of propellers driven by efficient electric powerplants, the VTOL propulsion system guarantees the relative quietness of the flight within urban metropolitan areas during take-off, landing, and transition from vertical to horizontal flight. Relatively comfortable departure from any place is possible without having to travel to the airport and going through a ground handling process. In forward horizontal flight, the propellers are locked in position with the lowest possible drag. The forward thrust is ensured by hybrid units with low fuel consumption, thanks to which the carbon footprint is significantly reduced compared to private business jetliners. Full operation of aircraft within urban areas and between cities presupposes a certain degree of implementation of ground infrastructure in the form of skyports (or vertiports), which will meet the relevant safety and security standards defined in future legislation adopted at ICAO level, but especially at national level – EASA regulations within the EU, adequate certification specifications from the FAA within the US, and other regulations of regulators and aviation authorities in states globally.

The following Figure 14 shows a time comparison of a journey from Prague to the Croatian island of Vis by a traditional jetliner and ZURI VTOL UA:

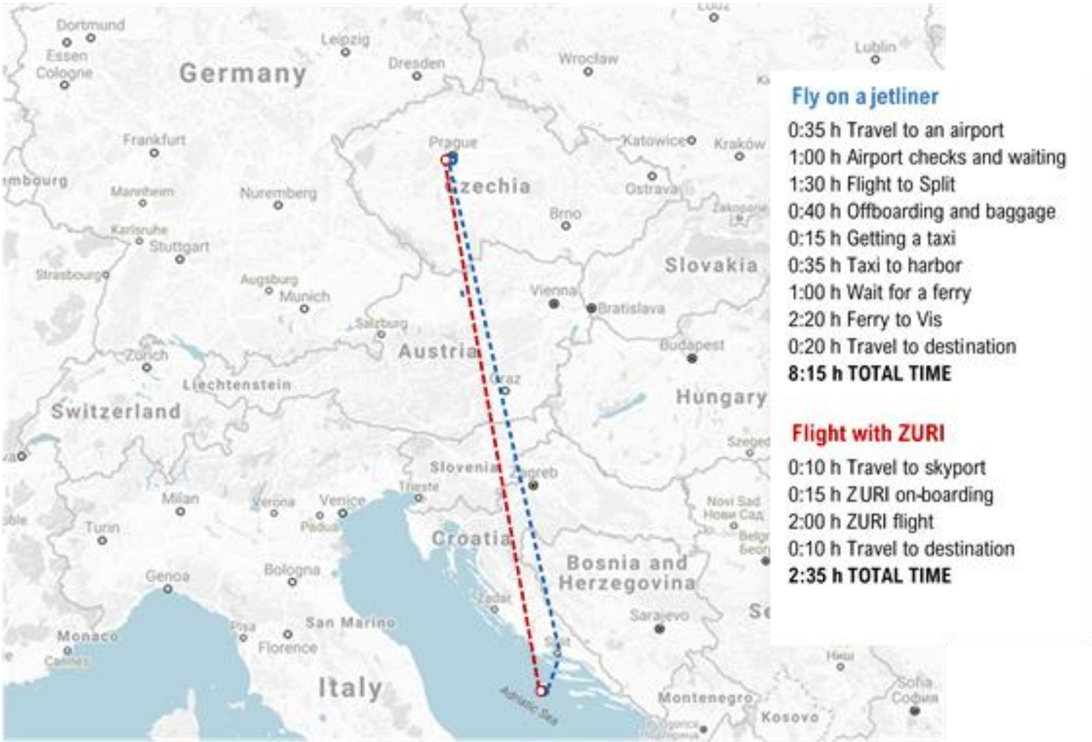
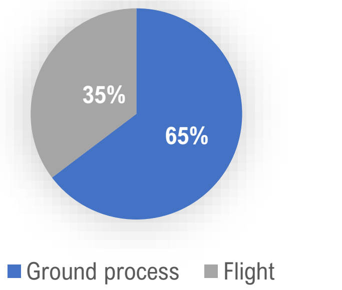
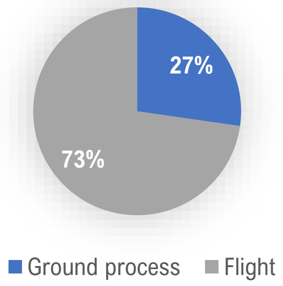
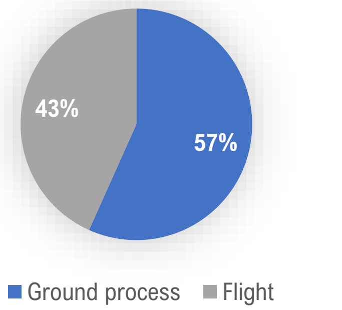
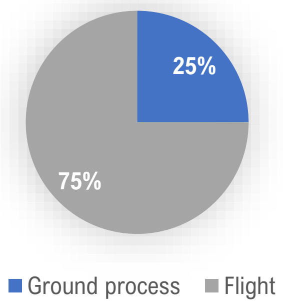
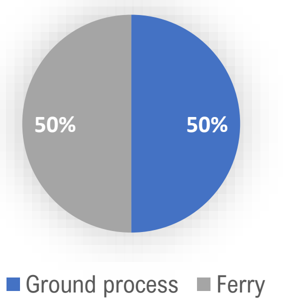
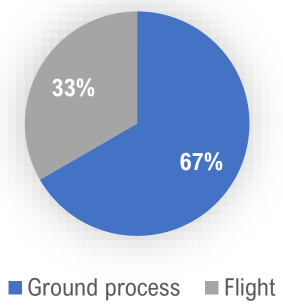


Figure 14 – Journey duration comparison – a jetliner vs. ZURI UA

The illustrative journey from Prague to the island of Vis by jetliner includes in the itinerary all aspects of traditional flying from the airport. The jetliner journey takes 8 hours 15 minutes, while the journey with ZURI takes only 2 hours 35 minutes. The itinerary includes a trip to the airport, check-in process before departure and after landing, a ferry ride to the island, etc. On the same trip using the ZURI UA, the customer can save more than 5 hours of time. ZURI also presents comparisons of other use cases, where the itinerary of the journey by ZURI UA is compared with a classic jetliner trip with the inclusion of the relevant ground process duration. For clarity, the following illustrative use cases of ZURI UA are presented in the thesis together with the percentage comparison of the shares of the time of ground handling processes and the flight time [65].

Table 10 – ZURI use cases with a comparison of itineraries

Business trip (300 km)		
Journey	*Jetliner*	*ZURI*
Geneva (Business center) – Monaco	0:20 h Taxi to airport 1:00 h Airport checks and waiting 1:00 h Flight 0:15 h Offboarding and helicopter boarding 0:15 h Helicopter transfer **2:50 h TOTAL**	0:10 h Travel to skyport 0:15 h ZURI onboarding 1:20 h ZURI flight 0:05 h Offboarding and baggage **1:50 h TOTAL**
Time share		
Holiday trip (550 km)		
Journey	*Jetliner*	*ZURI*
Prague – Cres, Croatia	0:35 h Travel to airport 0:50 h Airport checks and waiting 3:30 h Flight to Pula with stopovers 0:40 h Offboarding and baggage 0:45 h Waiting for ferry 0:45 h Ferry from Pula to Porozina 0:50 h Taxi to destination **8:05 h TOTAL**	0:15 h Travel to skyport 0:15 h ZURI onboarding 2:00 h ZURI flight 0:10 h Offboarding **2:40 h TOTAL**
Time share		
Island regions flights (65 km)		
Journey	*Car and boat*	*ZURI*
Phuket – Phi Phi Island, Thailand (Applicable to various island regions of the world such as Indonesia, the Maldives, the Philippines, or the states in the Pacific Ocean.)	0:55 h Travel from the airport to the harbor 0:45 h Wait for a ferry 2:00 h Ferry to Phi Phi 0:20 h Travel to the hotel **4:00 h TOTAL**	0:10 h Travel to skyport 0:15 h ZURI onboarding 0:15 h ZURI flight to the hotel 0:05 h Offboarding and baggage **0:45 h TOTAL**

Time share		

The graphs in the previous Table 10 of illustrative use cases show that in both cases a business trip and a holiday trip using a jetliner, the ground handling process represents up to about two thirds of the total travel time. Thus, of the total duration of the flight journey, the passenger "wastes" up to two thirds of the time being on the ground. In contrast, when using the ZURI UA, the ground handling process represents only about a quarter of the total travel time. Of course, as the distance flown increases, the time share of the ground handling process decreases even more. Ultimately, it can be stated that with the ZURI UA, the pre-flight and post-flight ground handling process takes a maximum of 30-40 minutes. Although the ZURI UA flight itself may take longer than a jetliner flight due to the lower ceiling of the aircraft and the slower flight speed, the inconveniences associated with the duration of the ground handling process are significantly shorter eventuating in the travel time of the journey being shorter as well. In terms of the nature of the obstacles that need to be overcome in transport in the third case, in the island regions of the world, the time shares are slightly different. The journey from Phuket to the island of Phi Phi in Thailand was chosen as an example. Phuket Airport is relatively far from the city itself, and there is no airport on Phi Phi Island that is capable of accommodating jetliners. Therefore, the only combination that can be used in the itinerary is the car and the ferry. For this reason, the graph on the left compares the time shares of the ground handling process vs. a ferry journey that has been selected equivalent to a flight. The time share in this case is half to half. Since the distance covered is only 65 km, the time share is different even in the case of the flight by ZURI UA, where the ground handling process takes up two thirds of the total travel time, while the short flight only one third. Here it is more convenient to compare the total journey time using car and ferry with the total journey time using ZURI UA. It is clear from the itinerary that the use of ZURI UA represents only less than a quarter of the duration of the journey by car and ferry, lasting four hours. ZURI UA manages the same journey in just 45 minutes.

The latter case is applicable to several island regions of the world, where ground infrastructure is lacking in sufficient quality, which makes transport often slow and therefore uninteresting for certain types of passengers. These are examples of countries also listed in the table – Indonesia, Maldives, Philippines, Federated States of Micronesia, Kiribati, and other oceanic and maritime regions. Enabling or introducing such a transport mode (eVTOL aircraft in general) could contribute to further economic development in the regions concerned by stimulating new business activities and opportunities, which could also result in an increase in the social level of the local populations. The construction of the necessary ground infrastructure and, in particular, the implementation of the necessary relevant legislation into the legislative frameworks of the given states is key and at the same time could be demanding in such regions.

At the moment, ZURI does not target the "ordinary" traveling public – middle-class customers traveling abroad, usually once or a couple of times a year. It is aimed in particular at the wealthier upper middle and rich class customers, for whom private flying is affordable and much more common, whether in recreational, sightseeing or business travel. The future of operations will depend in particular on the development of ground infrastructure in the form of skyports and their handling, a new airspace layout with the provision of relevant air traffic control services (although, due to the nature of the services provided by ZURI that are closer to ATM business jets and helicopters than to U-space-based UATM operations in metropolitan areas within the urban air mobility concept, this is not an inevitable precondition) and the affordability of such flights, which will ultimately determine the range of clientele that would use such a service. Based on this, it will be possible to determine the scope of operation or services provided to customers with the aim of sustainable mobility and efficient operation. In addition to the aspect of innovation, the introduction of a completely new service in the air transport market and technological development, it is necessary to look at ZURI and similar companies as a business model with the purpose of profit. For further development, the role of revenue management and marketing will therefore be essential for maintaining a stable financial condition, return on investment in new technologies, and sustainability between the supply and demand of services.